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REDUCING NON-ENERGY GREENHOUSE GASES

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ACKNOWLEDGEMENT AND DISCLAIMER

This report was prepared for the Ontario Ministry of Environment and Energy as part of a Ministry funded project. The views and ideas expressed in this report are those of the author and do not necessarily reflect the views and policies of the Ministry of the Environment and Energy, nor does mention of trade names or commercial products constitute endorsements or recommendation for use.

Caveat:

This report was completed in 1993. Some of the assumptions may differ from those used in the development of Canada's National Action Plan for Climate Change in 1994.

In particular, Canada's target for Greenhouse Gas Emissions excludes CFC's and other gases controlled under the Montreal Protocol, which are included in this report. Also the co-efficients assumed for Global Warming potentials (in CO_2 equivalents) are being revised upward in light of new evidence. Consequently the aggregate results should be interpreted in this light. Total non-energy gases as shown in the Action Plan will be a smaller share than is shown here. The individual measure analyses and results are unaffected by these factors.

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Purpose

The purpose of this study is to assist the Ontario Ministries of Environment, Energy and Treasury and Economics in formulating policies to reduce the non-energy emissions of greenhouse gases in Ontario.

Objective and scope

The objectives of the study are:

- to identify emission sources to be targeted for assessment of actions and measures;
- to identify and evaluate behavioural and technical actions to reduce non-energy emissions of greenhouse gases in Ontario;
- to estimate the potential quantities of greenhouse gas reductions which could be achieved and the costs of achieving them; and
- to review issues related to implementation including measures to induce the actions, timing and economic impacts.

The study focuses on emissions other than CO_2 from combustion for energy, which is addressed elsewhere by existing, on-going or proposed government of Ontario analyses. It considers the economic and environmental costs and benefits of the actions and measures that affect these emissions.

The greenhouse gases considered are carbon dioxide, methane, chlorofluorocarbons and their substitutes, and nitrous oxide. The time frame for the analysis is 1991 to 2005.

Methodology

The approach to the study consists of the following:

Identify major sources of greenhouse gas emission in Ontario—based on existing greenhouse gas inventories the non-energy anthropogenic sources of greenhouse gases are identified. These source emissions are standardized using carbon dioxide equivalent global warming potentials. Significant sources of greenhouse emissions are targeted for further analysis.

Identification of actions—through a review of the literature and consultation with industry and government, actions for reducing greenhouse gas emissions are identified. The potential effect of these actions will have on greenhouse gas emissions are evaluated on a per unit basis by source. Estimates of the total number of units affected by each action for each source are made.

Evaluation of actions—costs are estimated for the actions, and are expressed on a unit basis (i.e. dollars per tonne of carbon dioxide equivalent) for 2005 emissions. Where there are multiple actions aimed at the same emissions source, an estimate of the nature of the combined effect of the actions is estimated by calculating incremental unit costs. On this basis it is possible to order actions from the least to the most expensive per tonne of carbon dioxide equivalent.

Implementation issues—in principle, the actions evaluated are technical or behavioural changes that reduce the quantity of greenhouse gas emissions emitted in 2005. (In practice, it is often difficult to separate actions from policy measures.) Policy measures that might induce these actions to be taken are reviewed, and the impacts of the actions and measures are considered using the Ontario regional input-output model and experiences in other jurisdictions. Implementation issues such as timing of action, public perception, stock turnover rates, fairness considerations, level of government involvement required, technical maturity of the action and possible market imperfections are identified. Distributional considerations by sector and geography of measures are discussed and possible ways of mitigating these inequities are examined.

Sources of data and their limitations

Emissions—the major source of greenhouse gas emissions data is SENES (1992). Where necessary greenhouse gas emissions from specific sources are estimated. Sources for which no reliable estimate of greenhouse gas emissions are available are excluded from the analysis. There is considerable uncertainty surrounding the significance and forecast of various emissions and there is limited opportunity for reducing this uncertainty. Potential reductions in emissions for actions are based on a review of relevant literature and discussions with industry and government representatives. Often potential emissions reductions are process or source specific.

Global warming potential—greenhouse gas emissions are converted into carbon dioxide equivalents using IPCC (1990) 100 year time horizon global warming potentials. Indirect global warming effects are excluded. The 100 year time frame was considered to be most appropriate for policy analysis and for consistency with other studies undertaken. Shorter or longer time frames can be chosen altering the relative effects of the different greenhouse gases.

Costs of actions and measures—information regarding actions and measures are compiled from reviews of the literature and contact with industry and government representatives. The data may reflect the costs associated with development and testing of an action. Costs of actions cannot be applied to specific sources in Ontario. Many actions and measures for reducing greenhouse gas emissions are under development and not yet commercially available. The costs and effects of these actions are not known.

Implementation impacts—are based on secondary sources of information and the Ontario input-output model. The analysis of the impacts of implementing actions is limited by the reliability of the emissions forecast and lack of detailed cost data for most actions.

Findings

1) Non-energy greenhouse emissions account for about 30 per cent of total greenhouse emissions in Ontario and about 43 per cent of anthropogenic emissions (carbon dioxide equivalent). Chlorofluorocarbons and methane are the largest contributors. Based on carbon dioxide equivalency non-energy sources of greenhouse gases are significant contributors to global warming.

2) The most significant sources of emissions are chlorofluorocarbons for refrigeration and plastic foam production, and methane from landfills. Up to four times more chlorofluorocarbons are used for plastic foam insulation than is used as refrigerant in a domestic refrigeration unit.

3) Actions for reducing greenhouse gases from most major sources are available. In many cases these actions will be taken without further intervention to achieve other objectives. For example, elimination of N_2O emissions from adipic acid production, chlorofluorocarbons emissions (due to the Montreal Protocol) and the capture of landfill gas (CH_4).

4) There is a lack of data for quantifying actions for reducing emissions from some sources, particularly emissions from chlorofluorocarbon use and from industrial processes.

5) Actions identified in this study could reduce emissions by almost three-quarters if fully adopted. The costs of doing so are about 1.4 billion dollars per year in 2005 although some of the actions (composting and landfill gas recovery) result in a net benefit and others are not expected to result in any significant costs (alternatives to chlorofluorocarbons as blowing agents in plastic foams production).

6) Except for mobile air conditioning the impact of implementing actions to reduce chlorofluorocarbons is not significant for the sources examined. Greenhouse gas emissions from waste can be reduced and result in net benefits. The reduction of methane emissions from livestock can be implemented with minimal impacts.

7) The earlier actions which affect emissions from sources which store or "bank" greenhouse gases are implemented the greater the emissions reduction in 2005. Such actions should be implemented as soon as possible.

8) Adoption of the actions will result in reduction of greenhouse gas emissions beyond 2005.

Conclusions

1) Most of the sources and types of non-energy greenhouse gas emissions have been identified in current greenhouse gas emission inventories. Incomplete inventories exist for chlorofluorocarbons, fertilizer applications, and non-anthropogenic sources.

2) Actions to reduce non-energy greenhouse gas emissions can be implemented with minimal impact on the Ontario economy. Actions which reduce chlorofluorocarbon emissions from mobile air conditioners result in greater impacts on economic activity, employment and tax revenue resulting from the high capital and operating expenditures on related industries and consumers.

Recommendations

1) A complete inventory of sources and quantities of chlorofluorocarbons and industrial non-energy greenhouse gases should be undertaken to facilitate the evaluation of possible actions and measures on these sources.

2) Further research is required to determine the costs and impacts of measures for implementing the adopted actions.

3) Actions for reducing non-energy greenhouse gas emissions should be combined with actions for reducing energy related emissions to facilitate in the development of a comprehensive strategy for the reduction of greenhouse gas emissions.

4) Research into the dynamic impacts of implementing a strategy to reduce greenhouse gas emissions including the actions evaluated in this study should be undertaken.

Abbreviations

a	the SI symbol for annum (year)
CE	carbon dioxide equivalent
CFC	chlorofluorocarbon
DOC	digestible organic compounds
GHG	greenhouse gas
GWP	global warming potential (often relative to CO_2)
k	kilo (thousands)
M	mega (millions)
MSW	municipal solid waste
NUG	non-utility generator
t	tonne (1000 kilograms)

1 Introduction

1.1 The greenhouse effect

One of the most serious environmental issues facing society today is global warming. It is clear that there is a natural greenhouse effect which keeps Earth warmer than it would otherwise be. In addition to this background effects, emissions from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases : primarily carbon dioxide (CO_2), methane (CH_4), chlorofluorocarbons (CFCs) and nitrous oxide (N_2O). (see Table 1.)

These increases are expected to enhance the natural greenhouse effect, resulting in additional warming of Earth's surface (IPCC 1990). Carbon dioxide and other trace atmospheric gases (nitrous oxide, methane, chlorofluorocarbons and halocarbons) are transparent to incoming visible and ultraviolet solar radiation but readily absorb the longer wavelength (infrared) radiation that is re-emitted from Earth's surface. The subsequent downward refraction (or remission) of the infrared radiation and the absorption of infrared radiation raises the temperature of Earth's surface by more than 30°C over what it would be in the absence of the trace gases—the natural greenhouse effect.

That increased concentrations of greenhouse gases will affect global climate is certain, but the timing, the magnitude and locales of the impacts remain controversial. The knowledge of emission rates of greenhouse gases, and of the means and implications of preventing or adapting to greenhouse warming will play a vital role in enhancing understanding of societal implications of this effect.

1.2 Preventing or avoiding impacts from the greenhouse effect

In order to stabilize atmospheric concentrations, substantial reductions in global emissions of these gases are required, as is indicated in Table 2. Achieving these reductions will require significant changes in technology, lifestyles or both in developed countries, like Canada, which are highly dependent on energy sources and products that account for these emissions; Canada is identified with the fifth highest

Table 1 Summary of key greenhouse gases affected by human activities.

	Carbon dioxide	Methane	CFC-11	CFC-12	Nitrous oxide
Atmospheric concentration	ppmv[b]	ppmv	pptv[d]	pptv	ppbv[c]
Pre-industrial (1750-1800)	280	0.8	0	0	288
Present day (1990)	353	1.72	280	484	310
Current rate of change per year	1.8 (0.5%)	0.015 (0.9%)	9.5 (4%)	17 (4%)	0.8 (0.25%)
Atmospheric lifetime (years)	(50-200)[a]	10	65	130	150

SOURCE: IPCC 1990, p.xvi.

NOTES:
a. The way in which CO_2 is absorbed by the oceans and biosphere is not simple and a single value cannot be given.
b. ppmv=parts per million by volume.
c. ppbv=parts per billion by volume.
d. pptv=parts per trillion by volume.

per capita greenhouse gas emissions in the world, exceeded only by Lao People's Democratic Republic, Qatar, United Arab Emirates and Bahrain (WRI 1990:17).

Table 2 Emission reductions required to stabilise atmospheric concentrations at present day levels

Greenhouse gas	Reduction required
Carbon dioxide	>60%
Methane	15 - 20%
Nitrous oxide	70 - 80%
CFC-11	70 - 75%
CFC-12	75 - 85%
HCFC-22	40 - 50%

SOURCE: IPPC 1990.

In Ontario, a considerable amount of work has been done on assessing the potential for reducing greenhouse gas emissions associated with energy use, and the implications of measures for achieving the same. In addition, actions have been taken to reduce the release of other greenhouse gases, such as CFCs and NO_x (which

contains N_2O). However, these non-energy related sources of greenhouse gases remain significant.

In summary, emissions of greenhouse gases is a serious environmental problem facing global society, including Ontario. Sources of greenhouse gas emissions include both energy and non-energy related sources, and significant reductions in these are required to stabilize atmospheric concentrations at present day levels. Preliminary estimates for Ontario, and the experience reported in other jurisdictions suggest that non-energy sources of greenhouse gas emissions are significant, and merit investigation.

1.3 Objectives and scope of the study

The purpose of this study is to assist the Ontario Ministries of Environment, Energy and Treasury and Economics in formulating policies to reduce the non-energy emissions of greenhouse gases in Ontario.

The objectives of the study are:

- to identify emission sources to be targeted for assessment of actions and measures;
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2 Major sources of non-energy greenhouse gases

2.1 Types of non-energy greenhouse gases

The discussion below identifies types of greenhouse gas as a prerequisite for identifying actions and measures.

2.1.1 Chlorofluorocarbons

Chlorofluorocarbons are long lived synthetic chemicals containing chlorine, fluorine and carbon. They are released into the atmosphere from many sources including plastic foam manufacturing and use, air conditioning and refrigeration systems manufacturing, servicing and disposal, and as solvents, propellants in aerosols and sterilants. While emissions of CFCs are relatively small, their global warming potential (GWP) is significant, as much as ten thousand times that of carbon dioxide, tonne for tonne. This is due to their chemical and radiative properties and their life in the atmosphere, which may be several hundred years.

The major CFCs of concern are CFC-11, CFC-12, and CFC-113.

2.1.2 Methane

Methane is produced naturally as a product of anaerobic decomposition, or organic decomposition in the absence of oxygen, and as a byproduct of the petroleum industry.

Methane as the result of anaerobic decomposition has several sources: animals, particularly ruminants, expel significant quantities of methane as a byproduct of the digestion of fodder. Human and livestock manure gives off methane gas as it decomposes; and municipal solid waste also yields methane as it decomposes in landfills. Anaerobic decomposition also occurs naturally in wetlands and swamps.

Methane emitted from manure storage tanks and landfills poses a potentially serious explosive threat as well as an environmental threat. Collection and disposal of these emissions is already undertaken to ameliorate the explosive hazard: expansion of this collection and use of the gas for energy can provide an economic benefit and eliminate the environmental harm caused by atmospheric methane at the same time.

2.1.3 Nitrous oxides

Of all the greenhouse gases, the nitrous oxide flux is least understood. N_2O emission levels are also extremely uncertain; the primary biogenic sources identified are microbial soil nitrification and denitrification (OTA 1990). Anthropogenic sources of N_2O, although estimates are highly uncertain, include fossil fuel combustion (particularly coal), industrial processes such as nitric acid and adipic acid production, nitrogenous fertilizer use and direct use of nitrous oxide as an anaesthetic and a propellant.

The global warming potential of nitrous oxide includes not only direct radiative properties, but also indirect effects, as nitrous oxide contributes to ozone depletion in the upper atmosphere.

2.1.4 Carbon dioxide

As well as being a significant byproduct of fossil fuel combustion, carbon dioxide is stored in living organic matter and released during decomposition. Deforestation has been a leading cause of increasing concentrations of carbon dioxide in the atmosphere.

Carbon dioxide is also a product of the aerobic decomposition of sewage, animal waste and municipal solid waste and is given off during the combustion of biomass including waste incineration, wood residue incineration and forest fires.

Carbon dioxide emission during decomposition of organics, e.g., municipal solid waste and animal manure, have not been considered in this study. To the extent that forestry, for example, is practised sustainably, i.e., that sufficient trees are planted to replace those harvested, carbon dioxide given off during the decomposition of products made from trees, like timber, or given off during combustion, like CO_2 emissions from forest fires, is, in turn, taken up by living, growing trees. This is true of carbon dioxide emissions given off during human and livestock respiration, during decomposition of animal waste, and during decomposition of organic foodstuffs and

yard waste. To the extent, however, that organics are not produced sustainably, i.e., they are mined, CO_2 emissions given off during decomposition are net emissions to the atmosphere, at least in the short term.

Carbon dioxide is emitted during the manufacture of cement, as a byproduct of industrial fermentation processes and during kraft wood pulp manufacture. Coke and ammonia production also releases carbon dioxide into the atmosphere.

However, as carbon dioxide can be released from organic material, it can also be sequestered in growing or preserved organic material, such as forest products.

2.2 Global warming potentials

There are numerous compounds that contribute to global warming. In order to assess the relative significance of any emission, it is desirable to be able to express emissions of different compounds on a common basis, that reflects their contribution to the problem. One means of doing this is by using an index of a compound's global warming potential (GWP). There are several such indices, some based on physical factors, and some based on economic factors. The GWPs in most common use are those based on physical properties, developed by the 1990 Intergovernmental Panel on Climate Change (IPCC). These are presented in Table 3.

Table 3 Relative global warming potentials (GWP) of greenhouse gases

Greenhouse gas	Global warming potential
Carbon dioxide	1
Methane	21
Nitrous oxide	290
CFC-11	3500
CFC-12	7300
HCFC-22	1500

SOURCE: IPCC 1990

The warming effect of greenhouse gases depends on several factors: concentration, radiative absorption and emissions characteristics, and, in some cases, atmospheric chemical reactions (OTA 1990). Except for methane, the GWP, or CO_2 equivalence, of the greenhouse gases shown on Table 3 are direct radiative effects. The GWP for methane of 21 includes indirect effects, the result of secondary chemical reactions in the atmosphere. Methane in the atmosphere breaks down and reacts with other gases to produce, among others, carbon dioxide. In addition, climate change feedbacks may affect methane emissions levels, as emissions from biogenic sources of methane such as wetlands and rice paddies are sensitive to temperature, as are landfill methane emissions (OTA 1990).

Recent research (Lelieveld and Crutzen 1992; Ramaswamy, Schwarzkopf and Shine 1992; UNEP and WMO 1991) has found that there is still a great deal of uncertainty regarding the global warming potential of some greenhouse gases. According to new information , "many of the indirect global warming potentials reported in 1990 by the IPCC are likely to be incorrect" (UNEP and WMO 1991). However, recalculation of the direct GWPs for tropospheric, well-mixed, radiatively active species using updated lifetimes for methane, nitrous oxide, and the halocarbons (CFCs), indicate, with the exception of methane, only modest changes from the 1990 IPCC values (UNEP and WMO 1991). The inclusion of indirect radiative effects could significantly alter the 1990 IPCC GWP values for CFCs (Ramaswamy, Schwarzkopf and Shine 1992).

Lelieveld and Crutzen (1992) found that the GWP of methane is affected by its atmospheric life relative to carbon dioxide and the impact methane has on atmospheric chemistry, specifically the formation of ozone, water and carbon dioxide. They conclude that the indirect chemical effects on climate are much less than those

estimated by IPCC. Moreover, IPCC estimates of the GWP of methane fail to account for the effect of altitude on climate forcing and the reaction between methane on OH as a sink for both gases over time decreasing the life of methane in the atmosphere. The research undertaken by Lelieveld and Crutzen (1992) indicates that the chemical profile of the atmosphere effects the GWP of methane and that the IPCC estimate of GWP may be overstated by as much as 40 per cent.

Ramaswamy, Schwarzkopf and Shine (1992) estimated that CFCs and halons may actually have a much lower GWP than previously estimated and possibly a negative (contributes to cooling) GWP. The total radiative forcing of CFCs is the direct radiative effect plus the indirect chemical effect resulting from the destruction of ozone in the atmosphere which varies by altitude, latitude, cloud formation, moisture distributions and the amount of ozone present in both the stratosphere and troposphere. At lower altitudes in the stratosphere direct radiative forcing from CFCs is partially or fully offset by the negative forcing resulting from the depletion of stratospheric ozone. Moreover, the positive forcing potential of tropospheric (ground level) ozone is also offset by CFC destruction of ozone. As such the GWP for CFCs developed by IPCC and used in this study may overstate the global warming potential of CFCs.

In another study (UNEP and WMO 1991) also concluded that stratospheric ozone depletion induces decreased atmospheric radiative forcing, offsetting "a significant fraction" of the increased forcing attributed to emissions of greenhouse gases. They predicted that the decreased radiative forcing as a result of ozone depletion may be approximately equal to the radiative forcing caused by emissions of CFCs, the primary contributors to ozone depletion. This suggests that the net global warming potential of CFCs may be relatively small, even nil. However, the UNEP and WMO study is still under review, and there remains significant uncertainty regarding GHG emissions and the relative effects of greenhouse gases. The following discussion of actions to reduce greenhouse gases will include CFCs, still the primary cause of stratospheric ozone depletion.

2.3 Sources of greenhouse gas emissions

The Global Warming Inventory for the Province of Ontario (SENES 1992) and the Compilation of an Ontario Gridded Carbon Dioxide and Nitrous Oxide Emission Inventory (ORTECH 1991), are the available Ontario-specific inventories of greenhouse gas emissions. It is only recently that efforts have been made to quantify greenhouse gas emissions, and these inventories are best considered preliminary estimates.

Nevertheless, they provide a good starting point for identifying the relative order of importance of various emission types.

2.3.1 SENES inventories for CO_2, N_2O, CH_4 and CFCs

SENES (1992) estimates inventories for CO_2, N_2O, CH_4 and CFCs for 1988. The report includes estimates of uptake by sinks and methodologies for forecasting net GHG emissions. The methodology followed for the inventory is standard. The main finding of the inventory is summarized in Table 4.

A time scale of 100 years was chosen in the SENES report to express the GWP for the inventoried greenhouse gases. Different uncertainties in the GWPs for the various greenhouse gases could affect the relative importance of gases from a control point of view. In view of these factors, determination of the uncertainties in the emissions is vital.

2.4 Target sources of greenhouse gases

Of the anthropogenic non-energy related sources of greenhouse gas emissions inventoried, 17 sources comprise over 80% of the total. These sources (shown in Table 5 and Figure 1) are the primary focus of actions and measures to induce reduced emissions.

More than one-half of these emissions are CFCs, while CH_4 and CO_2 form the next largest components respectively. Nitrous oxide emissions are a relatively minor contributor, entirely accounted for by the production of ammonia and adipic acid. Since DuPont Canada is the only producer of adipic acid in the province, and has already announced plans to eliminate emissions of nitrous oxide during the manufacture of adipic acid, this source requires little attention (DuPont Canada 1992).

Table 4 Greenhouse gas emissions in Ontario, 1988

Sources	Absolute emissions (kt)						CO_2 equivalent (kt-CE)							
	CO_2	N_2O	CH_4	CFC-11	CFC-12	CFC-113	CO_2	N_2O	CH_4	CFC-11	CFC-12	CFC-113	Total	%
Energy-related														
Stationary fuel combustion	117 999.0	8.5	4.2				117 999	2 465	89				120 554	28.5%
Transportation	44 348.7	4.9	1.4				44 349	1 433	29				45 808	10.8%
Fossil fuel production	2 146.0	0.0	0.7				2 146	9	14			0	2 169	0.5%
SUBTOTAL	164 493.7	13.5	6.3				164 494	3 907	132				168 531	39.9%
Non-energy-related														
Industrial processes	19 433.0	21.2					19 433	6 160	0	0	0	0	25 593	6.1%
Product usage	2 160.0	0.6					2 160	171	0	0	0	0	2 331	0.6%
Waste	3 646.0	0.3	706.6				3 646	81	14 839	0	0	0	18 566	4.4%
Agriculture	0.0	1.2	338.9				0	334	7 117	0	0	0	7 451	1.8%
CFCs	0.0	0.0		2.9	4.6	3.4	0	0	0	10 080	33 580	14 448	58 108	13.7%
SUBTOTAL	25 239.0	23.3	1 045.5	2.9	4.6	3.4	25 239	6 746	21 956	10 080	33 580	14 448	112 049	26.5%
Biogenic														
Fires and wood decay	41 172.0	1.4	17.6				41 172	409	370				41 951	9.9%
Soils	0.0	222.8	0.0					64 612	0				64 612	15.3%
Wetlands	0.0	0.0	1 637.0					0	34 377				34 377	8.1%
Lakes and reservoirs	0.0	0.0	42.6					0	895				895	0.2%
Lightning over forests	0.0	0.5	0.0					139	0				139	0.0%
Wildlife	0.0	0.0	9.9					0	208				208	0.0%
SUBTOTAL	41 172.0	224.7	1 707.1				41 172	65 160	35 850				142 182	33.6%
TOTAL ALL SOURCES	230 904.7	261.4	2 758.9	2.9	4.6	3.4	230 905	75 813	57 938	10 080	33 580	14 448	422 762	

Source: SENES Consultants Ltd. 1992. *A global warming inventory for the province of Ontario.* Prepared for the Ontario Ministry of Energy, Toronto.

Table 5 Sources of anthropogenic non-energy greenhouse gases in Ontario, 1988

Sources	Absolute emissions (kt)						CO2 equivalence (kt)							
	CO2	N2O	CH4	CFC-11	CFC-12	CFC-113	CO2	N2O	CH4	CFC-11	CFC-12	CFC-113	Total	%
Fossil fuel production														
Natural gas transport	2 049.0	0.0	0.2				2 049.0	5.8	4.2	0.0	0.0	0.0	2 059.0	2.2%
Industrial processes														
cement manufacturing	2 720.0						2 720.0	0.0	0.0	0.0	0.0	0.0	2 720.0	2.9%
lime manufacturing	1 418.0						1 418.0	0.0	0.0	0.0	0.0	0.0	1 418.0	1.5%
ammonia production	1 596.0	8.7					1 596.0	2 523.0	0.0	0.0	0.0	0.0	4 119.0	4.4%
adipic acid production		11.7					0.0	3 378.5	0.0	0.0	0.0	0.0	3 378.5	3.6%
subtotal	5 734.0	20.4	0.0	0.0	0.0	0.0	5 734.0	5 901.5	0.0	0.0	0.0	0.0	11 635.5	12.3%
Product usage														
Raw CO2 usage	2 160.0						2 160.0	0.0	0.0	0.0	0.0	0.0	2 160.0	2.3%
Waste														
MSW landfills	1 792.0		569.8				1 792.0	0.0	11 965.8	0.0	0.0	0.0	13 757.8	14.6%
sewage treatment plants			129.6				0.0	0.0	2 721.6	0.0	0.0	0.0	2 721.6	2.9%
subtotal	1 792.0	0.0	699.4	0.0	0.0	0.0	1 792.0	0.0	14 687.4	0.0	0.0	0.0	16 479.4	17.5%
Livestock														
cattle respiration			125.7				0.0	0.0	2 639.7	0.0	0.0	0.0	2 639.7	2.8%
Livestock waste			54.6				0.0	0.0	1 146.6	0.0	0.0	0.0	1 146.6	1.2%
subtotal	0.0	0.0	180.3	0.0	0.0	0.0	0.0	0.0	3 786.3	0.0	0.0	0.0	3 786.3	4.0%
CFCs														
fugitive production				0.1	0.3	0.2	0.0	0.0	0.0	385.0	2 044.0	672.0	3 101.0	3.3%
refrigeration				0.4	1.9	1.3	0.0	0.0	0.0	1 400.0	13 870.0	5 460.0	20 730.0	22.0%
open cell foam				0.2	1.1		0.0	0.0	0.0	595.0	8 030.0	0.0	8 625.0	9.2%
closed cell foam				2.2	0.5	0.6	0.0	0.0	0.0	7 700.0	3 723.0	2 436.0	13 859.0	14.7%
solvents						1.1	0.0	0.0	0.0	0.0	0.0	4 620.0	4 620.0	4.9%
aerosol					0.8		0.0	0.0	0.0	0.0	5 913.0	0.0	5 913.0	6.3%
miscellaneous						0.3	0.0	0.0	0.0	0.0	0.0	1 260.0	1 260.0	1.3%
subtotal	0.0	0.0	0.0	2.9	4.6	3.4	0.0	0.0	0.0	10 080.0	33 580.0	14 448.0	58 108.0	61.7%
TOTAL SIGNIFICANT	11735.0	20.4	879.9	2.9	4.6	3.4	11 735.0	5 907.3	18 477.9	10 080.0	33 580.0	14 448.0	94 228.2	
(proportion)							12.45%	6.27%	19.61%	10.70%	35.64%	15.33%	100.00%	
TOTAL NON-ENERGY	25 239.0	23.3	1 045.5	2.9	4.6	3.4	25 239.0	6 746.0	21 956.0	10 080.0	33 580.0	14 448.0	112 049.0	
(significant / non-energy)							46.50%	87.57%	84.16%	100.00%	100.00%	100.00%	84.10%	

SOURCE: SENES Consultants Ltd. 1992.

NOTE: Values reported in this table may not correspond to numbers reported earlier as a summary of total greenhouse gas emissions for Ontario. Values presented here represent only *significant sources* selected according to criteria outlined elsewhere, and as such represent a sub-set of the total values from each source.

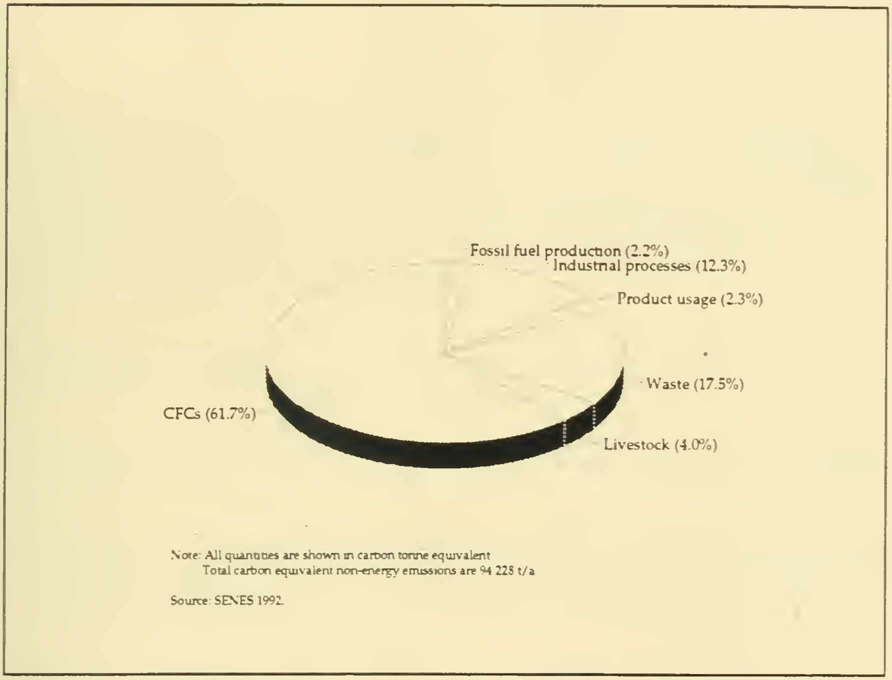

Figure 1 Significant sources of non-energy related greenhouse gases, Ontario, 1988

3 Actions to reduce CFC emissions

Actions are activities undertaken by individuals, firms or government which result in reduced emissions of non-energy greenhouse gases. For example, the reduction of CFC-11 used as a blowing agent for producing rigid polyurethane foams is an action. Actions differ from measures which are government initiatives or programs aimed at encouraging actions which reduce emissions of non-energy greenhouse gases. Government can undertake three types of policy measures to encourage actions to reduce non-energy greenhouse gas emissions:

- economic instruments which alter incentives for making choices regarding the purchase or provision of products or services;

- regulatory measures which change the range of products and services available or dictate the specific actions to be taken; and

- measures which increase the amount of information on the choice of products and services available, with the aim of encouraging people to make choices that achieve the policy option.

The distinction between actions and measures is important. For example collecting and combusting landfill gas is an action that will reduce the amount of methane emitted from landfills; government may implement measures, like banning organic wastes from landfill (regulatory measure) or charging a higher tipping fee for organic wastes (economic instrument), to prohibit or discourage the dumping of organic materials into landfills. The matching of measures to actions ensures that the measure effects the action and the reduction of non-energy greenhouse gases occurs.

This chapter considers criteria for selecting actions (section 3.1) dealing with CFCs in each of the major use categories.

3.1 Criteria for selecting actions

The actions chosen for reducing non-energy greenhouse gas emissions described in this and the following three sections were selected based on the following criteria:

- availability of information describing the action and the source of the action;
- potential for reducing global warming;
- opportunities for implementing the action prior to 2005;
- availability of cost data regarding the action; and
- likely indirect impacts of the action (ozone depleting potential, energy use, other environmental impacts).

3.1.1 Availability of information

A number of possible actions for each source of emissions of CFCs are still in development and testing. These actions may be available by 2005 but are in the preliminary research stage and still must undergo testing and trial operations. For example, vacuum panels are substitutes for CFC blown insulation in refrigerators and freezers. Although these panels are produced for commercial applications in some areas, problems exist in their reliability and durability. Further development and testing is required before vacuum panels can be considered a viable alternative to CFC blown insulation.

The actions selected have detailed information available regarding their potential for implementation and expected market penetration.

3.1.2 Potential for reducing global warming

The actions considered as replacements for CFCs have a lower GWP than the CFC they replace.

The GWP for CFCs used in this study are those presented in IPCC (1990). Currently, revisions to the GWP of CFCs is underway. Recent research (Ramaswamy, Schwarzkopf and Shine 1992) estimate that CFCs and halons may actually have a much lower GWP than previously estimated and possibly a negative (contributes to cooling) GWP. The GWP of CFCs is the direct radiative effect plus the indirect chemical effect resulting from the destruction of ozone in the atmosphere. As such the GWP for CFCs developed by IPCC and used in this study may overstate the global warming potential of CFCs.

3.1.3 Opportunities for implementing the action prior to 2005

The earlier some actions are implemented the larger the potential CFC emission reduction in 2005.[1] Actions were placed into one of three groups:

- commercially available on a wide scale in 1995;
- commercially available on a limited scale in 2005; and
- available after 2005.

Preference is given to actions which already have been demonstrated in the marketplace.

[1] Actions which mitigate emissions during the manufacture of products containing CFCs or from sources which are prompt emitters have the same impact on emissions in 2005 regardless of when they are implemented.

3.1.4 Cost data

Actions lacking cost data are not considered. Actions not considered are those which are not commercially available or are in the development and testing stage.

3.1.5 Indirect impacts

The indirect impacts of each action on health, safety and the environment are considered. Actions involving substitutes are selected based on the substitute's flammability, toxicity, and contribution to ozone depletion and low level smog formation. The impact of the action on energy use is also identified.

3.2 Plastic foams

The potential exists for eliminating all uses of CFCs in plastic foams production prior to 2005. CFCs are no longer used in the production of expanded and extruded polystyrene foams in Canada (Stevenson Kellogg Ernst & Young 1990; UNEP 1991), which constituted 45 per cent of rigid foam insulation use in 1988 (Abt Associates 1989). Possible actions for reducing and eliminating CFC use in rigid and flexible polyurethane foams are considered below.[2]

Consistent with the *Montreal Protocol* on substances that deplete the ozone layer the federal government has announced plans to ban CFC use as a blowing agent in flexible foams by the end of 1993, as a blowing agent in poured and sprayed plastic foam insulation by the end of 1995 and in rigid plastic foam insulating boardstock by 1994 (Environment Canada News Release 1990).

The Province of Ontario banned the use of CFCs in producing foam packaging in 1989 and in 1993 CFC use in all foam manufacturing will be banned (Madill 1992). The actions recommended in this report are consistent with the proposed provincial bans on CFC use in plastic foam production. All CFC use in plastic foam production

[2] Actions for reducing CFC use in phenolic and polyolefin foams are not included in this study due to the lack of reliable use and emissions data. Rigid polystyrene is not considered because CFCs are no longer used in its manufacture.

will be phased out by 1997 (by 1993 in Ontario). The banning of CFC use in plastic foam insulation manufacturing to achieve the *Montreal Protocol* targets will result in the adoption of the same actions proposed in this study for reducing CFCs as greenhouse gases.

3.2.1 Rigid polyurethane plastic foam

Rigid polyurethane foams are generally produced as a result of the exothermic reaction of isocyanates and polyols to produce gas bubbles as a blowing agent in the polymerising mixture. The blowing agent can either be chemically formed by the reaction, such as CO_2, or a physical blowing agent like CFCs can be added to the reaction. Often both blowing agents are used. In such instances CFCs are auxiliary blowing agents. CFC-11 is the auxiliary blowing agent in producing rigid polyurethane foams.

Rigid polyurethane foams are primarily used as insulation:

- appliance insulation (75 to 80 per cent of which is in refrigerators and freezers);
- construction laminated boardstock (between 60 and 75 per cent of which is used in commercial roof insulation);
- construction and transport sandwich panels (rigid insulation laminated facings);
- spray foam insulation (used for residential, commercial and industrial insulation and in insulated refrigeration trucks); and
- slabstock (insulation for pipes and storage tanks and refrigerated containers).

Emissions in Ontario

In 1988, 7 100 tonnes of CFCs were used for the production of rigid polyurethane foams (Environment Canada 1990a).

In Ontario the 1988 use of CFC-11 for rigid polyurethane foam production is estimated to be about one-half of national use, or about 3550 tonnes. A forecast of CFC-11 use for rigid polyurethane foam production in Ontario to 2005 is not available. As such, CFC-11 use in Ontario to 2005 for rigid foam production is assumed constant at 1988 levels. In the absence of actions to replace CFC-11 this suggests either a reduction in rigid polyurethane foam use in the province or greater efficiency in the use of CFC-11 for producing rigid polyurethane foam.

Rigid foam blown with CFC-11 is a closed cell foam which experiences a loss of about 5 per cent during manufacturing. The remaining CFC-11 is emitted at a rate of 4.5 per cent per annum for 20 years (Bach and Jain 1990). Due to a lack of time series data, 1988 CFC-11 use is used to approximate CFC-11 emissions from rigid polyurethane foams. Emissions in 1988 and 2005 are estimated at 3 183 tonnes (4.5% times 3550 tonnes times 20 years, plus 3550 times 5.0%).

Selected actions

Two actions are considered for reducing emissions of CFC-11 from rigid polyurethane foams:

- reduction of CFC-11 used as an auxiliary blowing agent; and
- substitution of HCFC-123 as the auxiliary blowing agent.

Reduction of CFC-11 :

The reduction of CFC-11 in the manufacturing of polyurethane foams achieves an immediate reduction in CFC-11 use and reduces emissions during manufacturing and over the life of the foam product. The reduction in CFC-11 use is achieved through an increase in the amount of water, a decrease in the amount of isocyanate used in the reaction or both. CFC-11 use can be reduced by as much as 50 per cent; from 15 to 6.5 per cent of content (as a blowing agent) in manufacturing construction boardstock; from 13 to 6.5 per cent of content (as a blowing agent) in appliance insulation; and up to 50 per cent of CFC-11 used in construction and transport sandwich panels and spray foam applications.

Slight increases in the operating costs of production are possible although likely offset by reduced use of CFC-11 (UNEP 1991). No change in capital costs is anticipated.

The thermal conductivity of insulation produced using less CFC-11 may increase 5 per cent.

The reduction of CFC-11 in rigid polyurethane foam production is a short term option since the production of CFC-11 is banned as of 1995. Only recycled CFC-11 is expected to be available for foam production after that date.

Substitution of HCFC-123 for CFC-11:

Rigid polyurethane foam blown with HCFC-123 has similar physical properties, thermal conductivity and aging (life) as foam blown with CFC-11.

HCFC-123 is a near drop-in alternative for CFC-11 use as a blowing agent in rigid polyurethane foam production. The capital costs of converting foam production using CFC-11 to HCFC-123 are minimal and zero if part of ongoing plant capital improvements. The costs of R&D are $110 000 for industry in Ontario (Stevenson Kellogg Ernst and Young 1988b).[3] The cost of HCFC-123 for the production of rigid polyurethane foam is expected to increase 25 per cent in the short term as a result of a shortage of HCFC-123. However no change in operating costs in the long term are expected as HCFC-123 becomes more readily available in the marketplace and its cost drops to that for CFC-11.

HCFC-123 may be toxic. ODP reduced to 0.02 of CFC-11. HCFC-123 is not flammable (UNEP 1991b).

3.2.2 Flexible polyurethane plastic foam

Flexible polyurethane is used as a cushioning material. It is formed using a blowing agent, carbon dioxide, generated through the exothermic reaction of water with a polyol and toluene diisocyanate. The greater amount of water used, the greater the volume of CO_2 formed. This results in more expansion and lower density foam. There are limitations to the increased formation of CO_2 in the manufacture of flexible polyurethane. The heat developed from greater amounts of water used in the production process results in degradation of the foam interior (scorching) and the formation of urea which limits the softness of the foam. CFC-11 is used as an auxiliary blowing agent, acting as a cooling agent for the water isocyanate exothermic

[3] One time capital costs and on-going expenses related to the research and development of the alternative.

reaction to reduce foam density (firmness) and increase softness of the foam. Other auxiliary agents are also used such as methylene chloride, acetone and methyl chloroform.

There are two processes for manufacturing flexible polyurethane foam, a conveyor system producing continuously poured slabstock or a system using moulds to produce a specific product (e.g., automotive seats).

Slabstock foams are used to produce low density super soft, and high density type foam products used in furniture, bedding, carpet underlay and motor vehicle interiors (UNEP 1991b).

Moulded foams are used in the manufacture of transportation vehicles (e.g., motor vehicle) industry for seat cushions, back cushions and headrests. About 10 per cent of moulded foam production is used in furniture manufacturing.

Emissions in Ontario

In 1988, 1 157 tonnes of CFCs were used for the production of flexible polyurethane foams (Environment Canada 1990). Slabstock production used about 717 tonnes (68 per cent) and moulded production about 440 tonnes (32 per cent) of CFC-11. About one-half of all flexible foams are produced in Ontario, or about 579 tonnes of CFC-11 in 1988. A forecast of use for flexible foam production in Ontario in 2005 is not available. As such, CFC-11 use in flexible foam manufacturing is assumed constant at 1988 levels. In the absence of actions to replace CFC-11 this suggests either a reduction in flexible polyurethane foam use in the province or greater efficiency in the use of CFC-11 for producing flexible foams.

Flexible polyurethane is an open cell foam. The CFC-11 contained within the foam is released in a relatively short period of time after the foam is manufactured. It is estimated that 25 per cent of emissions of CFC-11 occur during manufacturing; 83 per cent of the remaining CFC-11 is emitted during the year in which the flexible foam was manufactured and the remaining 17 per cent in the following year (Bach and Jain 1990). Assuming 1988 use levels of CFC-11, an estimated 579 tonnes of CFC-11 are emitted annually.

Selected actions

Three actions are considered for reducing emissions of CFC-11 from flexible polyurethane foams:

- reduction of CFC-11 used as an auxiliary blowing agent through process change and better management practises/housekeeping during the production process;

- substitution of HCFC-123 as the auxiliary blowing agent for CFC-11; and

- use of product substitutes such as natural and synthetic fibrefill and latex for flexible slabstock.

Reduction of CFC-11:

Certain housekeeping and maintenance activities help minimise blowing agent emissions. Routine maintenance of pumps, fittings and flanges, the unloading of the blowing agent through closed loop systems and avoiding the use of CFC-11 for flushing and cleaning the processing system will reduce CFC emissions. Restricting the density of foams and reformulating the foam to minimise the need for an auxiliary blowing agent also reduces CFC use. These actions can result in a reduction of CFC-11 use by up to two-thirds in flexible foam manufacture (UNEP 1991b).

It is assumed that there are no additional costs associated with the adoption of this action. Any increases in operating costs are expected to be offset by reduced use of CFC-11 (Stevenson Kellogg Ernst and Young 1988b)

No indirect impacts are expected from the adoption of this action.

Substitution of HCFC-123 for CFC-11:

HCFC-123 is expected to be the likely substitute for CFC-11 in flexible foam production (Stevenson Kellogg Ernst & Young 1988a). HCFC-123 has a GWP of 85 relative to CO_2, only 2 per cent the GWP of CFC-11. The use of HCFC-123 as the auxiliary blowing agent is not expected to affect the quality or durability of flexible foam products.

The estimated costs of adopting HCFC-123 by flexible foam producers in Ontario is about $275 000 for research, developing and testing (Stevenson Kellogg Ernst and Young 1988b).[4] HCFC-123 is technically compatible with CFC-11. No additional capital costs are expected. Operating costs may increase 1 to 2 per cent due to the expected higher cost of HCFC-123 relative to CFC-11. In the long term this increase in operating costs will diminish as HCFC-123 becomes more widely available.

HCFC-123 is not flammable and has an ODP of 0.02 relative to CFC-11. HCFC-123 may be toxic.

Product substitutes for flexible slabstock:

Alternative foams such as synthetic fibrefill and latex can replace flexible polyurethane foam slabstock use in selected furniture and bedding applications (Stevenson Kellogg Ernst & Young 1988b). The use of these substitutes will not alter the quality of the products but may diminish their durability. Some users of flexible foams are reluctant to try alternative products. These product substitutes will reduce slabstock use by about 5 per cent and reduce total CFC-11 use in flexible foam production by 4 per cent.

The market for cushioning materials is competitive. No significant change in the costs are expected.

No significant indirect impacts are expected from the adoption of this action. Use of natural fibrefill and rubber products as substitutes may decrease the available stocks of these natural resources.

3.2.3 Summary of plastic foams actions

The actions considered for reducing CFC emissions in the plastic foams industry and the potential reduction in emissions in 2005 are presented in Table 6.

4 One time capital costs and on-going expenses related to the research and development of the alternative.

Table 6 Potential reduction of CFC emissions in the plastic foams industry in 2005

Action	Decrease from base case (%)
Reduce amount of CFC-11 used to manufacture rigid foams in 2004	10%
Reduce amount of CFC-11 used to manufacture rigid foams in 2000	50%
Reduce amount of CFC-11 used to manufacture rigid foams in 1995	>100%[a]
Substitute HCFC-123 for CFC-11 in rigid foams in 2004	10%
Substitute HCFC-123 for CFC-11 in rigid foams in 2000	50%
Substitute HCFC-123 for CFC-11 in rigid foams in 1995	>100%[a]
Substitute HCFC-123 for CFC-11 in flexible foams in 2004	100%
Reduce CFC-11 use and emissions in flexible foams in 2004	67%
Use product substitutes for flexible foams to reduce CFC-11 use in 2004	4%

SOURCE: Action summary sheets Appendix A.

NOTES: a - emissions reductions are estimated at greater than the forecast emissions in 2005. The larger reduction is a result of the forecast constant emissions from 1988 to 2005 and the long period of times which CFCs remain "banked" in rigid (closed cell) foams (emissions in 2005 include CFCs banked prior to 1988).

3.3 Refrigeration and air conditioning[5]

In 1988 refrigeration and air conditioning accounted for an estimated 34 per cent (7000 t) of CFC use in Ontario (SENES 1992). Mobile air conditioners (almost 50 per cent) and commercial refrigeration (about 25 per cent) constitute the major users and emitters of CFCs from refrigeration sources (UNEP 1991). Actions for reducing CFC emissions from these two sources and domestic refrigeration and freezers are discussed below.

Consistent with the *Montreal Protocol* on substances that deplete the ozone layer the federal government has announced plans to ban all CFC production and import by the end of 1995 and use by 2000 (CCME 1992). All CFC use in new refrigeration systems will also be phased out by the end of 1995. The achievement of the *Montreal Protocol* targets will result in the adoption of the same actions proposed in this study for reducing CFCs as GHG from refrigeration systems. These actions are also

[5] Actions to reduce CFC emissions from cold storage and food processing, industrial refrigeration and commercial air conditioning (chillers) are not included in this study due to the lack of data on CFC emissions and the need to develop actions which are applicable for specific sources.

consistent with provincial regulations regarding the capture of CFCs from motor vehicles.

3.3.1 Mobile air conditioning

CFC-12 is used as a refrigerant in mobile air conditioning in passenger vehicles and light trucks. The air conditioning unit is typically installed by the vehicle manufacturer. Most mobile air conditioning units are not hermetic (closed) systems and must be recharged annually to maintain effectiveness.

Under the *Montreal Protocol* for the control and elimination of substances which deplete the ozone layer Canada committed to the banning of the use of CFCs in motor vehicle air conditioners beginning in the 1995 model year (Environment Canada News Release 1990). Ontario already requires the recovery and reuse of CFCs when motor vehicle air conditioning systems are serviced (since, 1 July 1991). Both of these policies are consistent with the actions proposed below. The achievement of the *Montreal Protocol* targets for the model year 1995 would effectively eliminate actions for replacing CFCs with non-CFCs in new motor vehicles or the retrofitting of motor vehicles produced after 1995.

Emissions in Ontario

In 1988, there were 272 000 new and 1.8 million existing motor vehicles (cars and light trucks) in Ontario equipped with air conditioning (MENY 1990; Abt Associates 1990). The average charge of CFC-12 for new vehicle air conditioners is 1.29 kg and the average remaining charge of CFC-12 in any given year in air conditioners in existing motor vehicles is 0.89 kg (Abt Associates 1990). For 1988 the estimated total use of CFC-12 in new motor vehicles is 351 tonnes and the existing bank of CFC-12 is 1616 tonnes.

The forecasted number of new vehicles containing air conditioning is 542 000 and the existing stock of vehicles containing air conditioning systems is 3.99 million in 2005 (MENY 1990; Abt Associates 1989a). The estimated total use of CFC-12 in 2005 in new motor vehicles is 700 tonnes (542 000 vehicles times 1.29 kg/vehicle) and the existing bank of CFC-12 is 3550 tonnes.

Emissions of CFC-12 can occur at three stages of a vehicle's life, manufacturing (less than one per cent of total emissions from mobile air conditioners), servicing and wrecking.

Mobile air conditioning units require frequent servicing to maintain a full charge of refrigerant. Emissions from mobile air conditioners occur at a rate of about 0.4 kg/a per vehicle per year. The remaining charge of refrigerant, 0.89 kg/vehicle, is emitted when a vehicle is wrecked and dismantled. The estimated emissions from the vehicle stock and wrecked vehicles, containing air conditioners in 1988 is 726 tonnes and 171 tonnes, respectively.

In 2005 existing motor vehicles with air conditioning are forecast to emit 1600 tonnes (0.4 kg/a times 3 990 000 vehicles) and disposed vehicles 365 tonnes (0.89 kg times 410 000 vehicles) of CFC-12.

Selected actions

Four actions are considered for reducing emissions of CFC-12 from mobile air conditioners:

- substitute HFC-134a in new motor vehicle air conditioning;
- substitute HFC-134a in current motor vehicle air conditioning stock;
- recover and incinerate CFC-12 prior to disposal of the motor vehicle; and
- recover and incinerate CFC-12 in current motor vehicle air conditioning stock.

Currently, there is no reliable incineration equipment for the destruction of CFCs (Madill 1992). For the purposes of this study it was assumed that the effective incineration of CFCs will be commercially available by 1995.

Substitute HFC-134a in new motor vehicle air conditioning:

HFC-134a is the most likely substitute for CFC-12 in mobile air conditioning (UNEP 1991a). HFC-134a has a GWP of 1200 relative to CO_2, 16 per cent the GWP of CFC-12. The system changes required for HFC-134a are relatively modest, the pressure/condensing characteristics of HFC-134a are similar to CFC-12 although enhanced condensing will be required to maintain performance and durability similar to CFC-12. A suitable new lubricant for HFC-134a must be used.

Minimal design changes are required to the current mobile air conditioning design to use HFC-134a. The estimated costs of new mobile air conditioning systems using HFC-134a result in additional capital costs of $115 and operating costs of $49 per vehicle/a (UNEP 1991a).

HFC-134a is not flammable and has an ODP of zero. Fuel vehicle efficiency may drop by 2 per cent. The change in fuel efficiency is included in the costs of the action.

Substitute HFC-134a in current motor vehicle air conditioning:

HFC-134a is the likely retrofit replacement for CFC-12 in mobile air conditioners. Air conditioning components which must be compatible with any new combination of refrigerant and lubricant include the desiccant, compressor, hoses, O-rings as well as the chemical stability of the system (UNEP 1991a). These components must be replaced for HFC-134a to perform adequately as a retrofit replacement for CFC-12.

The cost of retrofitting a mobile air conditioner for HFC-134a is $437 additional capital costs and $49/a additional operation costs. Capital costs include $436 dollars for retrofit and repair of the air conditioning system (UNEP 1991a) and 78 cents for the incineration of the recovered CFC-12.[6]

HFC-134a is not flammable and has an ODP of zero. Fuel vehicle efficiency may drop by 2 per cent. The change in fuel efficiency is included in the costs of the action.

Recover and incinerate CFC-12 prior to disposal of the motor vehicle:

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6 Estimated cost of incinerating CFCs, HCFCs and HFCs is $1 900 per tonne (Notorfonzo, 1992). Cost of incinerating CFCs based on $1 400 per tonne for PCBs plus an extra charge for handling a gaseous waste.

At present CFC-12 is not recovered from motor vehicles sent to the wrecker. When the vehicle is crushed the CFC-12 contained in the air conditioning system, 0.89 kg/vehicle, escapes into the atmosphere. Remaining CFCs can be recovered during servicing through the implementation of CFC capture and recovery systems at wrecking yards. These recovery systems can capture 95 per cent of CFCs contained in the air conditioning unit. There are an estimated 14 wrecking yards in Ontario.

The estimated cost of the capture and incineration of CFC-12 at the wrecker's yard is $5000 for the capture and recovery system, $49 dollars additional labour costs per vehicle (UNEP 1991a) and 78 cents incineration costs (Notorfonzo 1992).

The implementation of a capture and recovery system for vehicles sent to the wreckers can also be used to recover and recycle chemical substitutes developed to replace CFCs in mobile air conditioners.

Recover and incinerate CFC-12 from current motor vehicle air conditioning stock:

This action results in the permanent removal of air conditioning refrigerant from motor vehicles. At present CFC-12 is captured, cleaned and reused when motor vehicle air conditioning systems are serviced. Motor vehicle air conditioning systems require annual servicing as a result of leakages of refrigerants from the system. The remaining CFCs contained in the motor vehicle air conditioning system can be recovered through the implementation of a CFC capture and recovery system at garages and service stations. The captured CFC-12 is sent for incineration. These recovery systems can capture 95 per cent of CFCs contained in the air conditioning unit.

The estimated cost of the capture and incineration of CFC-12 at the garages and service stations is $5000 for the capture and recovery system, $49 dollars additional labour costs per vehicle (UNEP 1991a) and 78 cents incineration costs (Notorfonzo 1992).

The implementation of a capture and recovery system for vehicles sent to garages and services stations can also be used to recover and recycle chemical substitutes developed to replace CFCs in mobile air conditioners.

3.3.2 Commercial refrigeration

Commercial refrigeration includes self-contained stand alone equipment, remotely supplied display cases, and pre-fabricated (sectional/modular) walk-in cold storage rooms. Most of the equipment is factory assembled and installed on the job-site. Commercial refrigeration equipment ranges from single compressor units to multi-compressor parallel systems using reciprocating rotary screw compressors. Commercial refrigeration systems exclude industrial and domestic refrigeration systems.

Most commercial refrigeration systems are used in food merchandising and food service applications such as supermarkets, food stores, convenience stores, restaurants, cafeterias, commercial and institutional kitchens and delicatessens. Other applications include small systems supplying vending machines for beverages and food.

CFC-12 is currently used both for medium and high temperature refrigeration (-15 to 15 C). HCFC-22 is used for evaporator temperatures down to -37 C and R-502 is used for temperatures down to -45 C. The distribution between CFC-12, R-502 and HCFC-22 is as follows (UNEP 1991a);

CFC-12	79%
R-502	19%
HCFC-22	2%

CFC-12 is the preferred refrigerant since it is cheaper and less corrosive to the cooling system.

Emissions in Ontario

Commercial refrigeration systems account for about one-quarter of annual CFC use in refrigeration and air conditioning applications (UNEP 1991a). In 1988 it is estimated that 1680 tonnes of CFC-12 were used in Canada for commercial refrigeration applications. A further 462 tonnes of R-502 (51% CFC-115 and 49% HCFC-22) were used in commercial refrigeration in Canada.

In Ontario it is estimated that 50 per cent of Canadian CFC use or 840 tonnes of CFC-12 and 231 tonnes of R-502 were used (117 tonnes CFC-115 and 114 tonnes HCFC-22).

One estimate of emissions of CFCs from commercial refrigeration indicates that servicing is the major source of CFC emissions in commercial refrigeration (Table 7).

Table 7 Emissions from commercial refrigeration

Source	Factory assembled system	Field assembled system
Manufacture leak testing	5.4%	2.3%
Installation	5.4%	5.7%
Leakage	8.1%	23.0%
Service	54.0%	57.0%
Disposal (100% capture)	27.0%	11.5%
Total	100.0%	100.0%
Typical system charge	25 kg	230 kg
Total emission	90 kg	200 kg

SOURCE: UNEP 1991.

It is estimated that between 62 and 80 per cent of total emissions occur over the twenty year life of the refrigeration system. In smaller systems emissions are less since the system is hermetically sealed. Most R-502 and HCFC-22 applications are in self contained display cases with low leakages.

No estimates of emissions of CFCs from commercial refrigeration and air conditioning are available.

Selected actions

The most likely actions for commercial refrigeration and air conditioning are the following:

- Replace CFC-12 with HFC-134a. HCFC-134a can be substituted for CFC-12 in some commercial applications. However, HFC-134a is expensive, requires alternative lubricants and lowers energy efficiency.

- Replace CFC-12 with HCFC-22 in both medium and low temperature applications.

- Replace CFC-12 with ammonia. Ammonia is an attractive alternative since it is cheaper than CFC-12 or other alternatives, is an excellent refrigerant, increases energy efficiency and has no GWP or ODP. There are safety considerations, ammonia is toxic and flammable (UNEP 1991a).

These actions are not considered for analysis since no reliable data on emissions are available.

3.3.3 Domestic refrigeration and air conditioning

Domestic refrigerators and freezers are used to preserve food using a vapour-compressions cycle. CFC-12 is the refrigerant. The average refrigerator or freezer has a life of about 15 years and can operate for as long as 30 years. Since domestic refrigerators and freezers are hermetic (sealed) units there is little leakage of CFC-12. Typically the CFC-12 is emitted during the disposal of the appliance.

Domestic air conditioners (central and window) are also hermetic units which use HCFC-22 as the refrigerant. Domestic air conditioners are not included in the study.

Emissions in Ontario

No estimates of emissions of CFCs from domestic refrigeration are available.

Selected actions

The most likely actions for domestic refrigerators and freezers are the following:

- Replace CFC-12 with HFC-134a a near drop-in substitute. HFC-134a requires different types of oils (Polyethylene glycols) which contain more water than conventional mineral. Therefore a dryer is also needed to absorb the water quickly and efficiently to ensure operation of the appliance. That is, a molecular sieve desiccant. HFC-134a may not be as attractive when larger volumes of refrigerant are required since thermodynamic efficiencies drop and desiccant problems arise. As such energy consumption increases 5 to 8 per cent. Other alternatives—Dimethyl ether and HFC-152a—are flammable although they increase efficiency of the unit without redesigning the equipment. Energy savings of 3 to 7 per cent are possible.

- There is a large potential for release of CFC-12 (and CFC-11 insulation) from refrigerators and freezers upon disposal. CFCs can be captured, recovered and recycled. Such recovery is planned in many areas and is incorporated into waste management or demand side management practises for these appliances. In Ontario, many municipalities have a problem with the disposal and handling of white goods, including refrigerators and freezers. These municipalities collect their white goods separately and send them to special processing centres. CFCs can also be destroyed through incineration at temperatures greater than 590 C with subsequent flue gas scrubbing. The estimated cost of incinerating the CFC-12 captured in a domestic refrigerator or appliance is about $1/unit (Notorfonzo, 1992)

These actions are not considered for analysis since no reliable data on emissions are available.

3.3.4 Summary of refrigeration actions

The actions considered for reducing CFC emissions in the refrigeration and the potential reduction in emissions in 2005 are presented in Table 8.

3.4 Aerosols

Aerosols are considered prompt emitters, that is, the propellant and contents are released about six months after manufacture (Bach and Jain 1990). Aerosols include products used for personal, pharmaceutical, household, medical, commercial and industrial and pesticide use.

Table 8 Potential reduction of CFC emissions in refrigeration in 2005

Action	Reduction (%)
Substitute HFC-134a for CFC-12 in mobile air conditioners in 2004 - new vehicles only	10%
Substitute HFC-134a for CFC-12 in mobile air conditioners in 2000 - new vehicles only	53%
Substitute HFC-134a for CFC-12 in mobile air conditioners in 1995 - new vehicles only	100%
Substitute HFC-134a for CFC-12 in mobile air conditioners in 2004 - retrofit existing stock	78%
Capture and incinerate CFCs from mobile air conditioners prior to wrecking in 2004	18%
Capture and incinerate CFCs from mobile air conditioners at the servicing level in 2004 - existing fleet	78%

SOURCE: Action summary sheets, Appendix A.

Most aerosols use hydrocarbons (propane, n-butane, iso-butane or other blends or carbon dioxide) (USEPA 1990). In 1988 aerosols constituted 8 per cent or about 1600 tonnes (SENES 1992) of CFC use in Canada. In 1989 the use of aerosols and related products (spray solvents, compressed CFCs for foghorn applications) decreased to between 650 and 800 tonnes or less than 5 per cent of total aerosol use (Canada Gazette 1990). In January 1990 all uses of CFCs in aerosols were banned in Canada (exempting medical applications, research and some industrial applications (mould release agents, cleaners and solvents of electrical/electronic equipment and lubricants in mining applications) (Environment Canada 1990b). The use of CFCs in these exempted applications and products are expected to be phased-out by 1993 in Canada (Canada Gazette 1990).

A complete CFC ban for most aerosol use poses no technical problem and is not costly (Stevenson Kellogg Ernst and Young 1989b). No actions are considered for reducing aerosol emissions in 2005.

3.5 Sterilization

CFCs are used to propel sterilant gases for sterilization and fumigation at hospitals and at commercial sterilizers in Canada. Typically the sterilization process takes place in an enclosed chamber where the air is removed and pressurized gas introduced. After a period of time the gas is evacuated. Ethylene oxide (EO) is used for sterilization with CFC-12 (EO 12% and CFC-12 88%). The CFC-12 is vented through the chamber to evacuate all ethylene oxide which is both corrosive and flammable.

Consistent with the *Montreal Protocol* on substances that deplete the ozone layer the federal government has announced plans to ban CFC use as hospital sterilants by 1994 (Environment Canada 1990b). All CFC production and import will be phased out by the end of 1995 and CFC use by 2000 (CCME 1992). The *Montreal Protocol* target will result in the adoption of the same actions proposed in this study for reducing CFCs as greenhouse gases from hospital sterilization systems.

Emissions in Ontario

Sterilization is a prompt emitter of CFCs. In 1988, 484 tonnes of CFC-12 were used in Canada for sterilization (Environment Canada 1990a). It is estimated that 50 per cent of these emissions occurred in Ontario, resulting in emissions of 242 tonnes in 1988.

A forecast of future CFC-12 use for sterilization is not available.

Selected actions

The most likely actions for reducing CFC use in sterilization are the following.

- Use of disposable, pre-sterilized instruments for reusable, re-sterilizable instruments in health facilities. This action increases the costs of managing a health facility.

- Substitute the ethylene oxide/CFC-12 sterilant gas with a mix of ethylene oxide and CO_2 (10 per cent EO and 90 per cent CO_2). Sterilizing chambers would undergo retrofitting. CO_2 is a greenhouse gas.

- Use pure ethylene oxide for sterilization and purge with nitrogen. Sterilizing chambers would undergo retrofitting.

- Convert sterilization process from EO to gamma radiation. The use of gamma radiation requires the construction of new facilities. Health facilities would contract their sterilization requirements to these facilities.

These actions were not included in analysis due to a lack of reliable data on quantities emitted and conversion costs.

3.6 Solvents

Solvents containing CFC-113 are used in cleaning most electrical and electronic equipment as well as some medical and pharmaceutical equipment. CFC-113 is used because it does not react with the materials it cleans and it has a high degree of purity. The major processes requiring CFC-113 as a solvent are conveyorized vapour degreasing, cold cleaning, dry cleaning and open top vapour degreasing.

Consistent with the *Montreal Protocol* on substances that deplete the ozone layer the federal government has announced plans to ban CFC use as solvents for sensitive electronic equipment by 1994 (Environment Canada 1990b). All CFC production and import will be phased out by the end of 1995 and use by 2000 (CCME 1992). Meeting the *Montreal Protocol* target will require the adoption of the actions to reduce the use of CFCs as cleaning solvents. Many of the substitute actions will reduce not only the contribution to ozone depletion, but also to global warming.

Emissions in Ontario

Solvent use is a short term emitter of CFC-113. Most emissions occur in the first year of application with some emissions in the second year after initial use. SENES estimates Ontario emissions of CFC-113 from solvent use at 1 113 kt in 1988.

A forecast of future CFC-113 use for solvents is not available.

Selected actions

There are a number of actions available for reducing CFC use as a solvent. Many of these actions are applicable for use in specific production processes producing specific products. It is beyond the scope of this study to detail all of these actions (UNEP 1991c; Stevenson Kellogg Ernst & Young 1988a). The two most widely applicable actions for replacing CFC use as a cleaning solvent are the following:

- Terpene based solvents (isometric hydrocarbons) made from coniferous and citrus trees can substitute for CFC-113 use as a cleaning solvent. Terpene use can create a visible haze if proper ventilation systems are not in place. This action has long term potential.

- Aqueous cleaning using a mix of water and isopropyl alcohol can be used in many applications of cold cleaning, vapour and conveyorized degreasing in both electronic and non-electronic applications.

These actions could not be included in the analysis due to a lack of reliable data on quantities emitted, conversion costs and the site specific uses of solvents and alternative actions.

4 Actions to reduce methane emissions

This section of the report discusses actions to reduce methane emissions from the following sources:

- livestock, including respiration and manure;
- the natural gas industry;
- sewage treatment plants; and
- municipal solid waste landfills.

The list of actions discussed here are those actions most likely to be undertaken by 2005. Where data are unavailable for sources, an effort has been made to indicate the relative costs and potential emissions reductions of possible future actions. This information is based on a review of the literature and interviews with industry representatives and government officials. The information found in this Chapter is presneted in greater detail in Appendix A.

4.1 Livestock methane emissions

There are two types of actions to reduce livestock methane emissions: actions that reduce emissions on a per animal basis, such as increasing digestion efficiency and animal productivity, and actions that reduce the numbers of livestock, such as the use of bovine growth hormones like rBST and changing human dietary patterns to substitute meats from lower methane producing animals for those which produce more methane. Both types of actions are considered here.

4.1.1 Respiration

Opportunities for reducing the rate of methane emissions from livestock include increasing digestion efficiency and animal productivity, i.e., the amount of animal product produced per unit of feed. Specific options include (U.S. EPA 1989):

- supplementing the diets of grazing animals to correct nutrient deficiencies often found in lower quality forage;

- increasing digestion efficiency by substituting high concentrate feeds with low methane producing potential for high roughage feeds with higher methane producing potential in the diets of confined animals;

- supplementing diets with feed additives that increase digestion efficiency and reduce methanogenesis in the rumen, e.g. antibiotic compounds, sex and growth hormones and ionophores. Ionophores reduce feed requirements per unit of production, thus reducing corresponding methanogenesis, and inhibit methanogenesis by altering rumen fermentation patterns (Johnson, Branine and Ward 1991).

- improving reproductive efficiency (increased fertility rates, infant birth weights and decreased infant mortality rates all contribute to increased reproduction efficiency, necessitating a smaller breeding stock to maintain a given herd size); and

- decreasing animal morbidity and mortality by more efficient diagnosis and treatment of animal disease.

Of these actions, most of which have been actively pursued for many years for economic reasons, few are expected to achieve significant reductions in methane emissions in Ontario in the short-term. Beef and dairy producers in Ontario are considered to be among the most efficient in the world, and readily adopt new technologies and management practices to increase productivity or reduce management costs. The chief obstacle to implementing new feed additives or productivity enhancing supplements are delays associated with the regulatory approval process.

Emissions in Ontario

Emissions from livestock respiration in Ontario were estimated to be 147 kt in 1988. This is lower than SENES' estimate of 240 kt, chiefly due to the difference in respiration by chickens. Methane emissions from livestock respiration are shown in the following table.

Table 9 Estimated methane emissions from livestock respiration, Ontario, 1988

Type of livestock	Number	CH_4 emissions (kg/animal/a)	CH_4 emissions (t/a)
Horses (a)	300 000	18.000	5 400
Cattle (b)	2 250 000	58.475	131 568
Sheep	212 000	10.000	2 120
Goats (c)	32 460	5.000	162
Pigs (b)	3 230 000	2.311	7 465
Turkeys	2 665 000	0.010	27
Chickens	29 484 000	0.011	328
Total	38 173 460		147 070

SOURCES: OMAF 1991; Jaques 1992.

NOTES:
(a) Estimated population as of June 3, 1986 (OMAF 1991).
(b) Weighted average emission factor (Jaques 1991).
(c) Population as of June 3, 1986 (OMAF 1991).

Selected actions

Reduce rumen methanogenesis:

There may also be potential actions to reduce rumen methanogenesis unrelated to animal productivity:

- anticipated biotechnology may be able to manipulate rumen microflora to reduce methanogenic activity (Benzing-Purdie 1992); and

- chemical feed additives may fix hydrogen in the rumen, preventing the formation of methane at a molecular level (Chang 1992).

These actions are considered to be experimental.

Recombinant bovine somatotropin:

Recombinant bovine somatotropin (rBST) is a protein-based growth hormone that has been demonstrated to increase milk yields in superior cows by as much as 40 per cent (Deloitte and Touche, 1990). Several studies have demonstrated the economic benefits associated with use of rBST in dairy herds in Ontario (Deloitte and Touche, 1991; Stennes, Barichello and Graham, 1991). The Food and Drug Administration (Juskevich and Guyer, 1990) and the Office of Technology Assessment (OTA 1991) have found there to be no increased human health risks from dairy products from cows treated with rBST. rBST, however, has yet to be approved for use in Canada.

The net effects of rBST adoption in Ontario's dairy industry are difficult to predict partly because of the current system of milk production, processing and marketing in Ontario. The supply of milk is regulated by the Ontario Milk Marketing Board, which issues quotas for milk production to dairy farmers in the province.

With increasing milk yields, there are several possible impact scenarios related to the response of prices and quota levels to increased per cow milk production. It has been assumed here that administered prices, quota levels, levies, subsidies and farm gate prices are all unchanged. As production per cow increases the number of cows will be reduced since total production remains constant. In this scenario, the full economic benefits of rBST will be realized by producers.

This scenario was chosen because it is considered that, in the short term, rBST would be adopted gradually so that it would not be seen to have a one-time distinct impact on milk supply and, consequently, prices and quota values. As such, the Ontario Milk Marketing Board would not be required to respond directly to the perceived impacts of rBST adoption in Ontario.

4.1.2 Methane from animal waste

Animal wastes generated at farms where animals are confined, e.g., beef feed-lots, dairies, piggeries and poultry farms, are often handled as a liquid slurry, washed from barns and pens into storage tanks. To the extent that manure is stored or handled anaerobically, it is likely to give off methane and carbon dioxide as the organic matter decomposes.

Emissions in Ontario

SENES estimated methane emissions from animal waste to be 98.7 kt in 1988, increasing to 103.8 kt in 2005.

Selected actions

Actions to reduce methane from animal waste involve collecting the methane that is produced, or undertaking to prevent its production. These actions include the following:

- collecting biogas for energy or for flaring;
- implementing alternative manure application methods to prevent anaerobic decomposition;
- modifying manure storage facilities to prevent anaerobic decomposition

Collection of biogas:

About 50 to 90 per cent of methane generated from waste lagoons could potentially be recovered (EAJ 1990; USAID 1990; EPA 1989). Manure may also be collected and processed in anaerobic digesters, the CH_4 generated offsetting demand for other fuels. In China, for example, there were 3 to 4.5 million family-sized digesters in 1984 (World Bank 1985).

Alternative manure application:

Alternative manure application technologies, include injection rather than broadcast spraying or irrigation, to encourage aerobic decomposition and modifying anaerobic storage facilities to prevent methane formation. Alternative manure handling strategies are most practical for intensive farming, such as beef feed-lots, dairy, hog and poultry farms.

Alternative manure application technologies are the most promising in terms of economic and technical feasibility for reducing CH_4 emissions from animal waste (Hilborn 1992). The possibility that current application methods also increase natural sources of methane through soil run-off and leaching of organic matter into receiving waterways indicates that actions related to manure application may be worthy of future investigation. A study is presently underway to identify the environmental impact of alternative manure application methods (Hilborn 1992).

Anaerobic digestion of livestock wastes for biogas recovery:

Although there have been many studies of anaerobic digestion of animal wastes for biogas collection, the existing technology is not economically viable, especially where such digesters are retro-fitted to existing manure handling facilities (Ralph G. Winfield and Associates, 1986). Studies have been done of the possibility of centrifugally separating single-cell proteins from processed animal waste, as part of the biogas collection process, for use as a livestock feed supplement. Weight gains from livestock fed this supplement have generally been lower than expected with the result that this action is not considered to be a cost-effective source of dietary protein for livestock (Van Die 1987).

4.1.3 Other actions

Another action to reduce methane emissions associated with livestock rearing for human consumption is to modify our diet to minimise or, at least, reduce methane emissions associated with human dietary patterns.

Substitute pork or poultry for beef:

One way to minimise methane emissions from cattle is to substitute pork or poultry for beef consumption. An assessment of the effectiveness of this action requires a comparison of the per unit of production emissions associated with beef and its alternatives, and a comparison of their costs. The costs used in this analysis are producer prices for beef and pork dressed carcasses, which do not necessarily correlate with retail prices faced by the consumer (Leslie 1992; McCutcheon 1992). It should be noted that this is a first-run attempt at this analysis. A more detailed analysis would require an analysis of dietary requirements and the nutritional value of alternative proteins, including perhaps legumes and dairy products, and an analysis of secondary effects, such as energy inputs to beef raising and alternatives, fertilizers and pesticide use.

4.2 Methane emissions from the natural gas industry

4.2.1 Sources of emissions from the natural gas industry

The American Gas Association identifies the following sources of methane from the natural gas industry (AGA 1989):

During normal operations

- natural gas can be used to operate various types of instruments including valves, controllers and pressure regulators. A portion of this gas is emitted to the atmosphere during the operation of these instruments.

- Produced liquids that are collected in the gathering, transmission and distribution systems must be removed from the pipelines at specified locations. Natural gas is emitted to the atmosphere when the valves at these locations are opened to drain the liquids.

- Relief valves are used to prevent gas pipelines and equipment from exceeding their maximum operating pressure. In the event of excess pressure, the relief valve opens, emitting gas to the atmosphere, to relieve the pressure.

During maintenance and construction

- Natural gas may be purposely vented to the atmosphere during maintenance or new construction of gas process equipment and pipelines. The gas is evacuated to the atmosphere from facilities to provide a non-flammable and safe operating environment before maintenance or construction begins.

- Natural gas is emitted during the purging of pipelines and equipment prior to construction and maintenance.

Leaks

- Natural gas is unintentionally emitted to the atmosphere when pipelines, valves or associated equipment leak.

According to the AGA, each company employs inspection techniques and performs leakage surveys to identify points of natural gas leakage for economic reasons, i.e., to minimize lost gas. Companies routinely maintain data on lost and unaccounted-for gas, calculated by subtracting the total gas accounted for in sales from the total gas received from all sources, including discrepancies due to meter error, gas theft, variations in gas purchase and sale billing dates and periods, non-leak components and leaks.

Emissions in Ontario

Methane emissions during the transmission and distribution of natural gas in Ontario are a very small proportion of throughput (between 0.3 and 0.5 per cent), and among the lowest in North America (Hare 1992; Sherville 1992). Principal sources of emissions during the transmission and distribution of natural gas are from pneumatic instruments and third party damages. Emissions from Ontario's natural gas industry were estimated to be 3.22 kt in 1989 (See Table 10).

Table 10 Methane emissions during transmission and distribution in Ontario, 1989

	Gas released	
Resulting from:	kilotonnes	Percent
Pneumatic instruments	1.57	48.9%
Third party damage	1.39	43.4%
Purging in and out of service	0.17	5.2%
Regulator maintenance	0.07	2.1%
Miscellaneous operations	0.01	0.4%
Total	3.22	100.0%

SOURCES: Consumers Gas 1991a; Union Gas 1992; Statistics Canada 1990.

Selected actions

There remain limited opportunities to reduce emissions further. Possible actions include:

- replace permeable cast iron main-line pipe and pneumatic valves;
- reduce third party damages and improve leak detection programs;
- design to minimize the length of pipe which may require purging prior to and during construction and maintenance; and
- implement blowdown recovery projects.

The first action relates mostly to older gas delivery infrastructure; cast iron pipe is no longer installed, nor is pneumatic monitoring equipment that releases gas to the atmosphere. The other actions are relevant for even the newest infrastructure.

Replace permeable cast iron pipe and pneumatic valves:

Some of the older main-line gas distribution infrastructure in Ontario is cast iron. Recognizing that cast iron leaks more than newer steel and plastic pipe, Ontario's gas

utilities have embarked on programs to replace cast iron with steel and plastic pipe. The majority of cast iron pipe still in service in Ontario, in Metropolitan Toronto, is in the process of being replaced (Hare 1992; Sherville 1992; Consumer's Gas 1992). Pneumatic valves are also in the process of being replaced.

Reduce third party damages and improve leak detection :

Third party damages involve unintentional ruptures of gas pipelines by excavators. Gas utilities already sponsor "call-before-you-dig" services and information campaigns to reduce the incidence of accidental ruptures. The premise underlying leak detection programs, already undertaken by utilities in Ontario, is that if leaks are detected sooner, less gas will be leaked.

Minimise length of pipe requiring purging prior to servicing:

Prior to servicing, all components of the gas distribution system must be purged to minimise occupational hazard. The current practice is to pump a denser gas into the line, forcing the evacuation of natural gas through valves to the atmosphere. In Ontario, much of this vented gas is flared at the valve head, resulting in CO_2 emissions rather than CH_4. There is, however, expected to be some small fugitive emission of methane resulting from this procedure. If the system is designed to minimize the volume that requires purging before servicing, by installing shut-off valves at shorter intervals along pipelines and at compressor stations and delivery points, less methane may be released. There are no data available related to the relative cost and reduction potential of this action.

Blowdown recovery:

Blowdown recovery reduces gas releases prior to and during construction and maintenance, or to recover or flare vented gas. Safety precautions require that compressor piping be purged of gas whenever the compressor is not operating to provide safe working conditions for operators and maintenance personnel. This is normally accomplished by venting gas contained in compressor units and adjacent pipes to the atmosphere.

Union Gas has undertaken a blowdown recovery project at their Dawn Operations Centre to recover this gas, either by routing it to low pressure market lines, or, if other compressors are operating, into the fuel gas rack for these compressors (MacDonald 1992). In an emergency, gas may still be vented to the atmosphere. This project recovers over 15 000 m^3 of gas each year. The capital cost of this project was

approximately $1 million, and the economic benefits, in terms of the value of gas saved each year, amount to approximately $1550.

This blowdown recovery project was initiated for a number of reasons, methane emissions reduction among them. The primary reason, however, was to reduce the noise of blowdowns. Previously, the noise associated with venting gas at pipeline pressure constituted an occupational hazard and an environmental cost for people living nearby. Since the project was completed, the noise of venting has been virtually eliminated.

While cost and benefit data for other actions to reduce gas emissions from the natural gas industry are not available, the high cost of blow-down recovery is instructive in terms of indicating the approximate orders-of-magnitude of achievable emissions reductions and the costs involved. Actions not yet undertaken implicitly have relatively higher costs and relatively lower emissions reductions (MacDonald, 1992). Because the Canadian natural gas industry is among the most efficient and technologically advanced in the world, rates of unaccounted-for-gas and fugitive emissions are already as low as is economically and technologically feasible. Further reductions may be expected to be made only at high cost.

4.3 Methane emissions from sewage treatment plants

Sewage handling facilities and STPs are designed explicitly to minimize the production of methane to control odours and mitigate explosive hazards. Some STPs are equipped, however, with one or two-stage anaerobic digestion facilities as a means of treating sewage sludge. Methane produced in these digesters is used to heat the digester to optimal temperatures for methane production. Excess gas is vented and flared or stored (Archer 1992). Fugitive emissions from digesters are possible, but likely represent a small fraction of methane production, and a negligible contribution to total anthropogenic greenhouse gas emissions. Small emissions may also occur in the sewage handling system prior to entry in an STP, though these emissions have not been estimated and are considered to be negligible also.

No actions for reducing methane emissions from STPs are considered in this study.

4.4 Methane emissions from solid waste decomposition

4.4.1 Methane emissions from MSW landfills

Methane is generated during anaerobic decomposition of solid waste in landfills of degradable organic carbon in the waste. Landfill gas is primarily comprised of methane and carbon dioxide, and trace amounts of volatile organic compounds (Lashof and Tirpak 1990: 570). The amount of gas produced at a given site is a function of the amount and composition of landfilled waste, the degradable organic carbon (DOC) content of the waste and characteristics of the site, such as depth of fill, soil type, climate and precipitation.

In Ontario, several landfills have gas collection systems already in place, designed to mitigate odours and explosive hazards. Methane is flammable in concentrations between 5 and 15 per cent by volume in air at ordinary temperatures (Lashof and Tirpak, 1990) and poses an explosive hazard if not collected and controlled.

Emissions in Ontario

To estimate the reduction potential of both types of actions to reduce methane emissions from landfills, it was necessary to project base-line emissions to 2005. Following examples set out in the literature (Jaques 1992; MacViro 1991; Senes 1992), the EPA's Scholl Canyon model for predicting landfill biogas emissions was used to estimate future emissions in Ontario.

The Scholl Canyon model projects biogas yield to decline exponentially from the time of placement of the waste according to the following equation (MacViro 1991):

$$\frac{dL}{dt} = -kL_o^{-k(t-t_o)}$$

where:

L = the amount of gas left to generate per unit weight of refuse

k = the gas generation constant

t = time (years)

L_o = the ultimate biogas yield

t_o = initial time of landfilling

In order to use the Scholl Canyon model to estimate biogas emissions, it is necessary to make a number of assumptions regarding the decomposition environment within Ontario's landfills. Key factors are climate, such as mean daily temperature and average precipitation, waste composition, site characteristics and landfill management practices. Due to the unavailability of much of this data for specific landfills in Ontario, estimates have been based on best available data and the following assumptions (Jaques 1992; MacViro 1991):

- All waste generated in Ontario is disposed of in a single landfill, possessing characteristics of a typical landfill in Ontario based on available data. Disposal in this landfill commenced in 1941. A primary assumption of the Scholl Canyon model is that necessary bacteria for decomposition to take place are present when landfilling commences. Where this is true, a tonne of waste placed in an old landfill and a new landfill have the same ultimate biogas yield.

- Annual disposal figures for 1941 to 1989 are based on historical data (B.H. Levelton 1990). Disposal figures after 1989 are based on projections of population growth to 2010 and current per capita waste generation rates of 1.53 kg per day (0.56 tonnes per year).

- Except for a constant 258 700 tonnes per year that is incinerated in existing facilities, all waste generated in Ontario is landfilled. This assumption is necessary to estimate the impact of diversion of digestible organic wastes from landfills. (In estimating future emissions of methane from Ontario' landfills, Senes Consultants assumed the Ontario Government's waste diversion targets of 50 per cent by 2000 would be achieved, implying that a significant quantity of DOCs would be diverted.) A reduction in DOCs disposed of in landfills is simulated by an identical percentage reduction in the total waste disposed of in landfill.

- The ultimate biogas yield (L_o) is estimated to be in the range of 2 to 4 ft^3/lb of MSW, approximately 109 to 218 kg of methane per tonne of waste (MacViro, 1991). This is a lower estimated yield than that used by Senes (1992).

- The gas generation constant (k) for the Scholl Canyon model, the rate at which gas generation decreases from the time of disposal, is 0.07, resulting in a half-life, at which point half of the biogas is emitted, of 8 years (MacViro, 1991). This is higher than the constant chosen by Senes (1992), of 0.02, which resulted in a half-life of 38 years.

- The composition of landfill gas is typically in the range of 50 to 60 per cent (Jaques, 1992). For this study a value of 55 per cent was assumed.

- The average gas recovery efficiency of gas collection systems ranges from 30 to 80 per cent (MacViro 1991). For this study a value of 55 per cent was assumed. This suggests that gas recovery at Ontario's landfills will result in, at best, a 55 per cent reduction of methane emissions.

Having made these assumptions it is possible to estimate future landfill gas emissions and to evaluate alternative actions to reduce them.

It is estimated that landfills in Ontario emitted 447.6 kt of biogas in 1988, of which approximately 55 per cent (246.2 kt) was methane and 45 per cent (201.4 kt) was carbon dioxide. This is lower than SENES' estimate of 569.8 kt of methane in 1988. The difference in estimates can be attributed to differing assumptions regarding the organic content of municipal solid waste in Ontario, disposal rates, and methane generation rates. With a global warming potential 21 times that of CO_2, total landfill emissions are equivalent to 5170.2 kt of carbon dioxide, approximately 6 per cent of anthropogenic sources of non-energy related greenhouse gas emissions in Ontario in 1988.

Selected actions

Categories of actions to reduce methane emissions from landfills include collecting landfill gas emissions and reducing emissions by diverting methane producing wastes from landfills for alternative processing. These actions include:

- recovering landfill gas, for flaring or energy production;

- aerobic composting of digestible organic compounds (DOCs); and

- incineration, including energy-from-waste facilities.'

Landfill gas recovery:

Two of Ontario's largest landfill sites have gas collection and energy recovery systems: Brock West landfill has a 23 MW electrical power plant and a 15 MW facility was recently approved for the Keele Valley site (MacViro 1991). Brock West and Keele Valley service Metropolitan Toronto, and are among the largest landfills in Canada.

The economic feasibility of energy recovery depends on landfills satisfying the following criteria (MacViro 1991):

- accepts mainly municipal solid waste (residential and industrial/commercial/institutional);

- has a minimum design capacity of one million tonnes of refuse;

- has minimum landfilling area of 40 hectares; and

- has a closing date within the last ten years.

26 landfill sites in Ontario meet these criteria. It has been estimated that these sites might yield 250 million cubic metres of methane, or 179 kilotonnes (MacViro 1991). This amounts to approximately 30 per cent of estimated methane emissions from landfills in Ontario (SENES 1992).

The viability of gas collection systems at smaller landfills depends on the type of waste and landfilling method used, but also depends on access to the electricity transmission grid, in the case of electricity generation, or access to a suitable consumer, in the case of raw gas or steam heat production.

Costs and reduction potential have been estimated for a range of landfill sizes serving municipalities with populations from 4 500 to over 500 000 people. Since fewer smaller landfills will be proximate to the electricity grid than larger landfills, it was

assumed that 50 per cent of landfills receiving 2 500 to 25 000 t MSW/a would have access to the grid, and that the percentage of landfills having access to the grid would increase gradually until 90 per cent of those receiving 500000 and over would have access to the grid. Those landfills not having access to the transmission grid would be expected to collect and flare landfill gas. In addition, it was assumed that average gas recovery efficiency at all landfills is 85 per cent (MacViro 1991).

The cost and reduction potential of landfill gas recovery is summarized in Table 11.

Table 11 Cost and reduction potential of landfill gas recovery actions

Action	No. of Units[a]	Landfill capacity (tMSW/a)	Annual net cost	Reduction potential[b] (tCH_4 2005)
Collect and flare	4	2 500	$117 390	387
	8	5 000	$258 815	1 549
	7	10 000	$268 233	2 710
	11	25 000	$584 494	10 140
	2	50 000	$150 107	3 872
	1	100 000	$67 306	2 323
	1	150 000	$99 464	3 484
	1	500 000	$320 637	15 486
Recover LFG for energy	4	2 500	$40 757	387
	8	5 000	($47 716)	1 549
	7	10 000	($268 196)	2 710
	11	25 000	($1 522 907)	10 140
	8	50 000	($2 464 884)	3 872
	3	100 000	($2 224 110)	2 323
	5	150 000	($5 312 082)	3 484
	7	500 000	($24 702 063)	15 486

SOURCE: Data are from Appendix A.

NOTES: [a] "Units" are the number of landfills of the indicated capacity at which the action can be applied.
[b] Reduction potential is tonnes of CH_4 reduced in the year 2005 by the action.

Composting of food and yard waste:

Composting of DOCs reduces or eliminates methane emissions associated with the anaerobic decomposition of MSW. Composting produces a humus which may be used

as a soil enhancer or as refuse-derived-fuel. The scale of composters range from household capacity to industrial single or two-stage composters with a capacity of greater than 1000 tonnes per day of DOCs. Single stage composting processes can involve mechanical drums, which aerate the waste and provide a consistent temperature and humidity ideal for decomposition, or simply spreading waste on the ground thinly or in windrows to encourage aerobic decomposition. Costs and reduction potential have been estimated for household composting, municipal yard waste composting and municipal organic waste composting. These are summarized in Table 12.

Table 12 Cost and reduction potential of composting actions

Action	Unit capacity (t waste/a)	Annual net cost	Reduction potential (tCH_4 2005)
Household composting	0.36	($33 318 242)	41 093
Municipal yard waste composting	10 000	($9 701 707)	13 431
Municipal organic waste composting	44 000	$2 973 253	34 732

SOURCE: Appendix A.

Incineration of municipal solid waste:

Another option for diverting waste from landfill is to incinerate it. Although new incinerators are currently banned in Ontario, there are several operating energy-from-waste incineration facilities in the province. Energy is produced in the form of steam and electricity. Advantages, other than energy production and subsequent fuel displacement, include waste management advantages; although only approximately 30 per cent of the municipal solid waste stream is decomposed in landfills or by composting, 70 to 80 per cent of the waste stream is combustible and will provide energy, leaving from 20 to 30 per cent (by weight) of the waste stream to be disposed of by landfilling. As an option for methane emissions reduction, incineration is, however, relatively more expensive than landfill gas recovery or composting. Costs and reduction potential have been estimated for small (100 000 t/a), medium (250 000 t/a) and large (500 000 t/a) incinerators. These are summarized in Table 13.

Table 13 Cost and reduction potential of incineration

Action	Unit capacity (t waste/a)	Annual net cost	Reduction potential (tCH_4 2005)
Incineration (medium)	10 000	$77 698 311	9 530
Incineration (large)	500 000	$156 199 325	29 323

SOURCE: Appendix A

4.5 Relationships among actions

The relationship among alternative actions is complex. Some actions are more appropriate for larger communities served by larger landfills, while some actions' effectiveness is independent of scale. Some actions, if implemented, reduce or negate completely the effectiveness of other actions. For example, if municipalities collect organic waste separately for composting, the methane production potential at landfills will be reduced proportionately in the long term. Waste already placed in landfills will, however, continue to emit gas necessitating the installation of a gas recovery system, although the gas recovery system will collect less gas in the long term than if the organic waste had not been diverted, making the gas recovery system proportionately more expensive per unit of gas recovered.

If diversion actions and gas recovery actions are implemented in 2004, for the lowest present cost, diversion will have a negligible effect on gas production in 2005. If, however, diversion actions are implemented earlier, their effect will be more pronounced. The effect of organic waste diversion actions outlined in this study, implemented in 1995, on gas production in 2005 is shown in Table 14.

Table 14 Effect of diversion of waste in 1995 on landfill gas production in 2005

Action	Reduction
MSW incineration (medium)	11.31%
MSW incineration (large)	34.81%
Household composting	48.79%
Municipal yard waste composting	15.95%
Municipal organic waste composting	41.23%

For example, if medium-scale incineration of waste were to be implemented in 1995, it would result in a 11.3 per cent reduction in total landfill methane emissions in

Ontario in 2005.[7] If municipal organic waste composting were implemented in Ontario in 1995, total landfill methane emissions in Ontario in 2005 would be reduced by 41.2 per cent. The percentages shown above are not necessarily additive: if household composting is fully implemented, there will be less organic waste available for municipal yard and organic composting and vice versa. (These actions could, however, be considered complementary components of an organic waste management and methane reduction strategy with optimal implementation levels assigned to each action.)

[7] These diversion percentages were calculated using the Scholl Canyon landfill gas generation model assuming technical waste diversion potential for each waste diversion action as outlined in Appendix A. Every tonne of waste that is diverted from landfill, to incineration or elsewhere, will reduce total landfill emissions in Ontario. The diversion percentage reported is intended to be applied as a fraction of total landfill methane emissions in Ontario in 2005, resulting from waste diversion actions implemented in 1995.

5 Actions for reducing carbon dioxide emissions

CO_2 emissions arise from production processes in industry. The industries considered as non-energy sources of GHG are cement, lime, pulp and paper, ammonia production, and raw CO_2 use. For each industry, the industrial process leading to GHG emissions is described along with the major uses of the product. This is followed by a discussion of possible actions identified for each industry.

Actions considered can be classified into the following categories:

- product substitution;
- process changes; and
- emission control measures.

The manufacturing processes for each industry are described to identify the basis of the GHG emissions. The potential for reduction of other non-GHG emissions associated with the process are identified also.

5.1 Concrete

5.1.1 Cement manufacturing

The basic raw materials required for portland cement are calciferous materials such as limestone, and chalk, and materials rich in silica, such as clay. Additional materials include sand, waste bauxite and iron ore which are used to adjust product mix. The overall process used to produce the cement clinker product involves grinding the raw materials, mixing them and heating the mixture in a kiln at high temperatures to produce the cement. The cement clinker is cooled and ground in a pulverizer to produce a powdered cement. Combustion of fuel is required to produce the high temperatures from the hot combustion gases in the kiln. The basic reactions occurring in the kiln are:

- a drying process that evaporates free water and combined water in the clay;

- a calcining process which uses a thermal decomposition reaction to breakdown calcium carbonate to produce carbon dioxide and calcium oxide; and

- a clinkering zone where the main reaction between lime and clay occurs to produce cement clinker (high temperatures 1427 °C to 1650 °C).

The major GHG emitted is CO_2 from the calcination reaction in the calcination zone in the kiln. (Austin 1984; CPCA 1989). Cement manufacturing accounts for about 2 per cent of the non-energy emissions in Ontario from the calcination reaction (SENES 1992).

The major market for portland cement is concrete used in construction. In Ontario there are 7 cement plants. Plant data for 1989 are available on the portland cement industry including:

- capacity summary by process and kiln age;

- capacity summary by fuel usage;

- provincial ranking by clinker and finish grinding;

- kiln capacity ranking; and

- detailed plant information by company (Portland Cement Association 1990).

Emissions in Ontario

Based on an emissions factor of 0.5 tonnes CO_2 per tonne of concrete produced (Environment Canada 1992) emissions of CO_2 in Ontario in 1988 were 2 700 kilotonnes (SENES 1992). The forecast emissions of CO_2 in 2005 is 4 040 kilotonnes (SENES 1992).

Selected actions

Reduction of CO_2 emissions are theoretically possible from scrubbing, radical changes in manufacturing by substituting different raw materials, such as ground granulated blast furnace slag, or by product substitution. The following actions are considered feasible to reduce carbon dioxide emissions.

Ground granulated blast furnace slag :

Ground granulated blast furnace (GGBF) slag is a cementatious material produced as a residual waste as a of result of steel-making. GGBF slag can be substituted for portland cement in making concrete. The combining of GGBF with portland cement has two processing advantages: 1) each material can be ground to optimum fineness and 2) the proportions of each can be adjusted to suit particular project needs.

GGBF slag consists of silica and alumina combined with calcium and magnesium oxides. The cementatious properties of GGBF slag is determined by its composition and the rate at which the molten steel is cooled when it comes form the blast furnace. To maximize the cementatious properties of GGBF slag it must be chilled rapidly as it leaves the blast furnace, converting it to a fine aggregate.

Blended concretes in which GGBF slags are combined with portland cement are (i) slag-modified portland cement (GGBF slag less than 25 per cent of total weight, (ii) portland blast-furnace slag cement (25 to 70 per cent GGBF slag) and (iii) slag cement (70 per cent or more GGBF slag). These concretes have been used for over 100 years and have excellent service records (ASI 1987). GGBF slags are usually substituted for portland cement on a one-to-one basis by mass.

The proportion of GGBF slag used in concrete is dictated by:

- the purpose for which the cement is used;
- curing temperature;
- grade (activity) of GGBF slag;
- time of setting and finishing (GGBF slag increases the setting time);

- sulphate resistance; and

- the control of expansion due to alkali silica reaction.

GGBF slag improves the workability and placability of cement compared to concrete not containing GGBF slag and reduces bleeding since it is finer than portland cement. Concrete containing GGBF slag also is less permeable, improves sulphate resistance of concrete and reduces potential expansion of concrete due to alkali—silica reaction.

One drawback of concrete containing over 30 per cent GGBF slag is a loss in strength and durability while curing. The extent to which GGBF slag affects strength is dependent on the grade (composition and fineness) of GGBF slag and the ratio it is used in mixture. The amount of water and curing temperature are also factors influencing the strength of concrete containing GGBF slag.

Concrete containing GGBF slag exhibits similar freezing and thawing and resistance to deicing chemicals, has no impact on corrosion of steel and has similar modulus of elasticity as concrete not containing GGBF slag (ASI 1987).

Concrete containing 25 to 70 per cent GGBF slag can be used as a partial replacement in all concrete applications presently using portland cement except where high early strengths are required. Ultimately the use of GGBF slag depends upon the desired qualities of the concrete (ASI 1987). GGBF slag/portland cement mixtures can also be used for ready-to-mix concrete, precast concrete products and for mortars and grouts.

Replacement of cement with slag cement will result in reduction of energy used (less product produced) and a corresponding reduction in emissions of VOC, NO_x, SO_x, particulates and lead.

Currently, Kock Minerals Company, a manufacturer of water-granulated blast slag cement, and National Slag Limited, use slag as a partial substitute for cement. Kock Minerals receives its slag from Algoma Steel in Sault Ste. Marie and National Slag Limited handles the slag generated from the steel producers in southern Ontario. The slag used is chemically similar to portland cement but with a higher silica content (Kock Minerals 1992).

Reduction:

Improved concrete characteristics can extend the life of structures. At the present, structures are being repaired and replaced before the functional life of the structure.

The development of high performance concrete has improved the durability for use in structural applications (CPCA, 1991).

Reducing the demand for cement will result in reductions in emissions from the basic process.

Reuse and recycle:

Demolished concrete structures can be *reused* in protecting shorelines. Broken floor slabs and sidewalks can replace quarried stone in dry stone retaining walls applications. Technologies exist to recycle concrete structures but the economics have been a barrier for this option (CPCA 1991).

If the economics became attractive, reusing cement would result in a reduction of cement produced.

Cement kiln dust

Residual cement kiln dust (CKD) obtained from the stack gases can be sold as a by-product or can be disposed in a landfill. Current markets for the CKD include fertilizers, treatment of municipal sewage, soil sweetening and as stabilizing agent for soil and sludge (CPCA 1991).

Use of CKD in the applications mentioned above would reduce the demand for lime; hence, reductions in emissions associated with lime production could be expected.

5.2 Lime

5.2.1 Lime manufacturing

Lime is produced by calcining limestone (calcium carbonate) or dolomite (a combination of magnesium and calcium carbonates) at high temperatures to drive off carbon dioxide and producing calcium oxide (quicklime). This process is carried out in a kiln. There are two basic kiln designs:

- Rotary kiln — a long cylindrical kiln angled slightly from the horizontal. The kiln is fired using a fuel source and the kiln feed enters at the top end. Carbon dioxide is a by-product gas along with combustion gases.

- Vertical or shaft kiln — these are short, vertical cylinders lined with refractory materials. There are four basic zones in a shaft kiln including : (1) stone storage zone, (2) preheating zone (3) calcining zone and (4) cooling and discharge zone.

Other designs include rotary hearth kiln and the flousolids kiln. The non-energy source of carbon dioxide is from the calcination reaction.

The major users of lime include the following sectors (National Lime Association 1992):

- steel manufacture;

- soil stabilization;

- building construction;

- air pollution control; and

- water treatment.

Some uses of lime absorb atmospheric carbon dioxide to form calcium carbonate. The uses included the following:

- precipitated carbon carbonate;

- construction (soil stabilization, finishing lime, mason's lime);

- environmental applications (flue gas sulphur removal, water purification); and

- agriculture.

These uses can be considered as sinks in the carbon cycle.

A study is presently being conducted by ICF Incorporated for the U.S. EPA that is concerned with GHG emissions in the lime and cement industry. The study was concerned with an emissions inventory for the cement and lime industry in the United States.

Emissions in Ontario

There are nine major producers of lime in Ontario. Emissions of carbon dioxide from lime production were 1418 kilotonnes in 1988 and are forecast to increase to 1854 kt by 2005 (SENES 1992).

Selected actions

At present there are actions planned to mitigate non-energy GHG emissions from lime manufacturing (Personal communication, National Lime Association). No actions were considered for the lime industry.

5.3 Pulp and paper

5.3.1 Pulp and paper manufacturing

The production process for pulp and paper operations at an integrated Kraft mill consists of the following steps (CERI 1989):

- raw material harvest, collection and transportation;
- wood preparation, debarking and chipping;
- pulping;
- bleaching;
- pulp stock preparation;
- sheet preparation;
- pressing;
- drying;
- finishing, coating, cutting and binding.

The pulping process involves breaking wood down by disintegrating the lignin to produce the cellulose fibre mass called pulp. Pulping can be performed using mechanical processes or by the use of chemicals, heat or pressure to produce various grades of fibres. The Kraft process is the most common chemical pulp process in Canada.

Wood chips are dissolved in a heated chemical solution of sodium sulphate called white liquor. After the pulping process in the digester, the spent or black pulping liquor contains lignin and sodium sulphate. Evaporated and compressed black liquor is sprayed into a boiler where the organics are burned off leaving behind smelt. Green liquor is produced from dissolved smelt by regeneration in the causticizing stage. Lime produced from a kiln is added to liquor at the causticizing stage. Carbon dioxide is emitted during the Kraft process from black liquor combustion in the furnace.

The major markets for Kraft pulp include:

- printing and writing paper;
- paperboard.

Emissions in Ontario

CO_2 emissions from the combustion of spent pulping (black) liquors in the furnace is estimated at 441 kilotonnes in 1988 and 666 kilotonnes in 2005 (SENES 1992).

Selected actions

Several actions are considered for reducing CO_2 emissions from the combustion of black liquors. These actions are not included in the analysis due to a lack of information on potential reductions in GHG emissions and cost data.

Recycle :

An increase in the recycling of forest products (paper products — old newspapers, fine paper, old corrugated cardboard) results in a decrease in demand for virgin pulp. This decreases the amount of Kraft pulp produced.

Process change:

The most promising technological changes in chemical pulping is in the chemical recovery stage. Research is being conducted in the gasification of the black liquor. Two examples of this technology are the Champion International gasification system which turns black liquor into green liquor and heating gas although recausticizing is still required in the cycle and plasma gasification which does not need the causticizing step but requires more energy (generally electricity). Development of plasma gasification is not expected due to high capital and operating costs (CERI 1989).

Implementation of the Champion system will result in reduced energy requirements but not non-energy CO_2 emissions. The plasma technology will lower non-energy carbon dioxide emissions but increase emissions associated with the increased consumption of energy.

5.4 Ammonia

5.4.1 Ammonia production

The processes for producing ammonia were described above in Section 6.4.1. CO_2 is emitted as a by-product from the CO_2 regenerator.

The three ammonia plants in Ontario capture the CO_2 regenerated from the CO shift converter through CO_2 scrubbing and stripping (McBeath 1987). The CO_2 is used for urea manufacture or sold for making carbonic acid, dry ice, etc. Surplus CO_2 is released into the atmosphere. One plant in Ontario, Nitrochem, generates CO_2 from its nitrogen scrubbing unit. These emissions are released into the atmosphere.

Emissions in Ontario

Carbon dioxide emissions from ammonia production in Ontario are estimated at 1600 kilotonnes in 1988 and 1400 kilotonnes in 2005 (SENES 1992).

Selected actions

All three Ontario manufacturers of ammonia use control technologies to mitigate emissions of CO_2.

Capture and recover CO_2 :

Carbon dioxide emissions from ammonia manufacturing can be reduced through the sale of CO_2 captured, rather than released into the atmosphere, during the CO_2 regeneration process for use in urea manufacturing, carbonic acid, dry ice etc. There are no costs associated with this action since CO_2 is already captured and sold into these markets. Greater demand for CO_2 in these markets will reduce the amount of CO_2 released into the atmosphere from ammonia production.

This action results in a transfer of greenhouse gas emissions from ammonia production to another source and is not considered further.

Currently there are no technically feasible actions for the control of CO_2 emissions from nitrogen scrubbing during ammonia manufacture.

5.5 Raw CO_2

5.5.1 Raw CO_2 use

Carbon dioxide is available from a number of sources including:

- recovery from synthesis gas in ammonia production;
- recovery as a by-product in the production of substitute natural gas from gasification of coal;
- recovery from production of ethanol by fermentation; and
- recovery from natural wells.

High purity CO_2 is obtained by using an absorption system (Austin 1984).

The main uses of CO_2 in all forms include:

- production of urea;
- pressurizing oil wells for secondary oil recovery;
- refrigeration (solid CO_2);
- beverage carbonation (liquid); and
- fire extinguisher (liquid) (Austin 1984).

Emissions in Ontario

About 1000 tonnes of CO_2 were emitted through raw CO_2 use in Ontario in 1988 (SENES 1992). A forecast of emissions in the year 2005 is not available.

Selected actions

No actions were identified during the study for reducing emissions from raw CO_2 use.

6 Actions to reduce nitrous oxide emissions

Nitrogen oxide emissions arise from production processes in industry. The industrial processes considered to be the most significant are adipic acid production, nitrogenous fertilizer use in agriculture, N_2O use as an anaesthetic and ammonia production. For each industry, the industrial process leading to GHG emissions is described along with the major uses of the product. This is followed by a discussion of possible actions identified for each industry.

Actions considered can be classified into the following categories:

- product substitution;
- process changes;
- emission control measures.

The manufacturing processes for each industry are described to identify the basis of the GHG emissions. The potential for reduction of other non-GHG emissions associated with the process are identified also.

6.1 Adipic acid

6.1.1 Adipic Acid Production

Adipic acid production emits N_2O during the production process. Current control measures remove about 50 per cent of N_2O emissions. The single manufacturing plant in Ontario (DuPont) has announced plans to virtually eliminate N_2O emissions from their plant within the next five years. DuPont is evaluating the available technologies used to implement this reduction.

Emissions in Ontario

SENES (1992) estimates 1988 N_2O emissions from adipic acid production to be 11 700 tonnes. Emissions of N_2O in 2005 are expected to be zero.

Selected actions

Since N_2O emissions from adipic acid production will be eliminated within five years no mitigation actions are considered.

6.2 N_2O

6.2.1 N_2O use as an anaesthetic

Efforts to control N_2O emissions are under way primarily to reduce occupational exposure. Some of the recommended measures will also reduce emissions from hospital anaesthetic operating rooms. The Ontario Ministry of Labour is currently undertaking a study regarding N_2O exposure in dental offices but results of that study are not yet available.

Emission in Ontario

N_2O used as an anaesthetic in hospitals and dental offices account for 600 tonnes of N_2O emissions in Ontario in 1998 and are expected to reach 700 tonnes by 2005.

Selected actions

No actions are considered for N_2O anaesthetic use.

6.3 Nitrogenous fertilizer

6.3.1 Nitrogenous fertilizer use in agriculture

When nitrogenous fertilizer is applied on agricultural soils, N_2O emissions occur. Significant N_2O emissions may also arise from domestic (residential) fertilizer use but are not included in the analysis.[8] N_2O is released in the soil by microbial processes resulting from the reduction and oxidation of mineral nitrogen (Jaques 1992). When nitrogenous fertilizer is applied to agricultural soils a majority of the nitrogen is oxidized to nitrate before it is adsorbed by plants. This process is called nitrification. The remaining oxidized nitrogen is released to the atmosphere as N_2O.

The level of N_2O emissions from fertilized soils depends on:

- fertilizer type and amount;
- application techniques and timing;
- tillage and irrigation practises;
- use of pesticides;
- soil and crop type; and
- amount of residual nitrogen in the soil (U.S. Department of Commerce 1991).

N_2O emissions vary widely depending on how these factors interact.

Several options are available to increase fertilizer efficiency or reduce the need for fertilizer, thereby reducing emissions of N_2O. The extent to which emissions can be lowered is not known (U.S. Department of Commerce 1991).

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8 It is assumed that domestic fertilizers are included in the data of total fertilizer use in Ontario on which the emissions from agriculture fertilizer use are based.

The environmental benefits of reduced use of nitrogenous fertilizers is reduced contamination of surface and groundwater and lower emissions of GHG into the atmosphere.

The linkages between the ammonia industrial sector and the fertilizer/agricultural sector are beyond the scope of this study but are important (in terms of determining the efficacy of product substitution in relation to greenhouse gas emissions and crop yields).

Emissions in Ontario

It is difficult to estimate N_2O emissions from fertilizer use due to the factors (fertilizer type, application technique, etc.) which affect the rate of emissions. SENES (1992) calculates N_2O emissions from fertilizer applications on agricultural lands in Ontario at 1150 tonnes in 1988. ORTECH (1992) estimates emissions of 1733 tonnes of N_2O in 1988 and Jaques (1992) estimates total N_2O emissions for Ontario at 2462 tonnes in 1990.

SENES estimates emissions of N_2O from fertilizer use in 2005 at 1300 tonnes.

Selected actions

Fertilizers are often used inefficiently in agriculture. Several actions are available for reducing N_2O emissions from fertilizer use:

- efficient fertilizer application;
- low N_2O-emitting fertilizers;
- slow-release fertilizers;
- nitrification inhibitors; and
- leguminous sources of nitrogen (O.T.A. 1990).

Efficient fertilizer application:

Nitrogenous fertilizers are applied to agricultural crops to increase yields. The effectiveness of fertilizer use (the amount of nitrogen in fertilizer applied to the soil taken up by plants) can be improved by determining the optimal amount of fertilizer to use based on:

- the amount of nitrogen already available in the root zone;
- how much nitrogen the crops actually use;
- the best time during the growing cycle to apply fertilizer; and
- the depth at which the fertilizer should be applied (U.S. Department of Commerce 1991).

Low N_2O-emitting fertilizers:

Anhydrous ammonia accounts for 13 per cent of fertilizer use and 63 per cent of total N_2O emissions resulting from fertilizer applications while urea accounts for 42 cent of total fertilizer use and only 8 cent of N_2O emissions[9] (ORTECH 1992). Significant emissions reductions may be possible by changing the type of nitrogenous fertilizer used on agricultural soils.

Applicability of this action and reductions in N_2O emissions depend on a variety of factors including type of crop and soil conditions. Further research is required.

[9] Fertilizer use by type in Ontario is as follows (ORTECH 1992):

Fertilizer Type	N_2O (t/a)
anhydrous ammonia	1 095
urea 140	
ammonium nitrate	150
solutions	236
ammonium sulphate	2
monoammonium phosphate	39
diammonium phosphate	71
10-30-40	0
Total	1 733

These data show that anhydrous ammonia has the largest potential for reduction presumably by substituting an equivalent fertiliser which has lower equivalent N_2O emissions.

Slow-release fertilizers and nitrification inhibitors:

Slow release fertilizers and nitrification inhibitors can reduce emissions of N_2O by allowing for more efficient plant uptake. In certain conditions the reduction in nitrogen losses are up to 30 per cent.

Slow release fertilizers and nitrification inhibitors may only delay emissions of N_2O until after the nutrient uptake ceases and the crop is harvested.

Leguminous sources of nitrogen:

By growing "nitrogen fixing" legume crops such as peas or beans in rotation with grains the need to apply fertilizer is less. The use of crop rotation using legumes would also lower emissions resulting from fertilizer production and conserve soil.

There is a lack of data on emissions reduction resulting from legume cultivation. Legume cultivation also may have limited applications in Ontario.

6.4 Ammonia

6.4.1 Ammonia production

Ammonia is the base product from which most nitrogen-containing chemical products are derived. Synthetic ammonia accounts for the major source of ammonia. Atmospheric nitrogen and hydrogen are reacted to form ammonia using ammonia catalysts. The major supply of hydrogen is from methane and other hydrocarbons. In Canada, 98 per cent of synthetic ammonia comes from the catalytic reforming of natural gas (McBeath 1987). Another source of ammonium compounds are coking plants which produce ammonia liquors, ammonium sulphate and ammonium phosphates. There are three ammonia producers in Ontario.

The major use of ammonia is in the nitrogenous fertilizer industry (Austin 1984). Other uses include heat tracing, paper pulping, nitric acid, nitrates manufacture, nitric ester and nitro compounds, explosives and as a refrigerant. The major fertilizers include ammonia, ammonium nitrate, ammonium sulphate, ammonium phosphates (MAP and DAP) and urea. In Ontario about 78 per cent of ammonia production is used in manufacturing nitrogenous fertilizers (McBeath 1987).

Greenhouse gas emissions from ammonia production include a small amount of N_2O vented from the primary reformer stack.

Emissions in Ontario

Emissions of nitrous oxides from ammonia production are estimated at 8.7 kilotonnes in 1988 and 7.7 kilotonnes in 2005 (SENES 1992). These estimates do not include possible increases in the use of ammonia as an alternative refrigerant to chlorofluorocarbons in commercial and industrial refrigeration and air conditioning applications.

Selected actions

N_2O emissions from ammonia production are not controlled. There are no viable actions for the control of N_2O emissions from the reformer stack during ammonia manufacturing.

7 Costs of actions and measures

7.1 Actions to reduce GHG emissions

7.1.1 Estimating the costs of actions

Annual costs in 2005 for emission reductions that year are estimated by considering the capital and operating costs of actions, the lifetime of technologies employed, and the delay between the time of implementation and achievement of emission reductions. In order to identify the most economically attractive actions, their incremental unit costs in dollars per tonne of carbon dioxide equivalent were calculated.[10]

Because some of the actions apply to the same emissions source, it was necessary to assess how actions interact. This was done by considering actions that apply to a single source together, and estimating the costs of moving from the least expensive to the most expensive option, and considering the incremental unit cost. For example, with flexible foams made using CFC-11, it is possible to cut CFC use in half with reduction actions[11] (FLEX2, FLEX3), or a substitute blowing agent—HCFC-123—may be used (FLEX1) (see Table 16). The first two actions will reduce CFC use (and hence emissions) and are free ($0.00/t-CE), whereas the second eliminates all CFC-11 use and involves a modest equipment cost. In this example, the equipment cost that is part of the second action is spread not over all CFC use, but only that remaining after the zero cost reduction actions are taken.

Similarly, for some actions, including chemical substitution of CFCs it is possible to achieve greater reductions with earlier implementation, but at a greater cost. For example, the cost of using HFC-134a in mobile air conditioners is about $28/t-CE if implemented in 2004 and about $38/t-CE if implemented in 2000, reflecting the opportunity cost of capital between implementation and realized emissions reductions in 2005. However, implementation in 2000 will affect more vehicles, so reductions

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[10] The details of the methodology used are described in Appendix B.

[11] Actions are described using the action codes in Appendix A (e.g. FLEX1).

are greater. A complete description of the modelling framework used to determine the relative costs of actions is presented in Appendix B.

Based on the analysis of the incremental cost of each action, a number of actions are found to be unattractive and will never be selected. These actions have a higher cost and lower emissions reductions than at least one other action that applies to the same emissions source. The selected set of actions is presented in Table 15. Some actions considered were never selected and are not presented in Table 15. For example, household composters are estimated to have a net negative cost and installing them in 2004 results in much lower CH_4 emissions reductions from landfills than does installing them in 1995. Installing them earlier results in not just lower emissions, but also larger economic savings. Consequently, installation of home composters in 2004 is never preferred.

7.1.2 The major actions for reducing GHG emissions

The largest sources from a quantity perspective are some of the CFC-related actions, accounting for almost 85 per cent of the (carbon dioxide equivalent) reductions associated with the selected actions (Table 15). As noted in Section 2.2, there is considerable uncertainty about the global warming potential of CFCs. Although many of the actions for CFC considered will be taken anyway to avert stratospheric ozone depletion, their attractiveness as actions to reduce global warming may be limited. If the global warming potential of CFCs is near zero, the incremental reductions for CFCs indicated in Table 15 will almost disappear.

As would be expected from the inventory data in Table 5, waste related actions are the next most significant types, followed by actions affecting smaller sources. Methane recovery from landfill results in the largest incremental emissions reduction from waste-related actions and household composting reduces emissions from waste-related activities at least cost. In assessing these actions, it should be noted that although the "other" actions as a group have an average incremental unit cost that is lower than the average for CFCs or waste related actions, there is quite a bit of variation in incremental unit costs within the three groups in Table 15.

Table 15 Summary of incremental reductions and costs by action, within major groups

Action code	Description	Incremental reduction (kt-CE/a)	Percent of all actions	Incremental unit cost ($/t-CE)
FLEX1	Flexible foams-sub	1 977	3.0%	$0.01
FLEX2	Flexible foams-reduction	81	0.1%	$0.00
FLEX3	Flexible foam-reduction	1 358	2.1%	$0.00
MOBILE1	Mobile air conditioners-new	5 771	8.9%	$64.53
MOBILE2	Mobile air conditioners-new	5 112	7.9%	$33.71
MOBILE3	Mobile air conditioners-new	1 293	2.0%	$28.30
MOBILE4	Mobile air conditioners-retro	9 443	14.6%	$47.57
MOBILE5	Mobile air conditioners-wrecks	2 533	3.9%	$8.64
MOBILE6	Mobile air conditioners-red	10 738	16.5%	$19.23
RIGID1	Rigid foams-reduction	567	0.9%	$0.00
RIGID2	Rigid foams-reduction	2 261	3.5%	$0.00
RIGID3	Rigid foams-reduction	2 832	4.4%	$0.00
RIGID6	Rigid foams-chem sub	11 041	17.0%	$0.00
Sub-total for CFC actions		**55 006**	**84.8%**	**$22.89**
LAND13a	MSW inc. from 2004 (100 kt/a)	41	0.1%	$517.32
LAND13b	MSW inc. from 2004 (100 kt/a)	17	0.0%	$378.33
LAND13c	MSW inc. from 2004 (100 kt/a)	173	0.3%	$260.31
LAND15a	MSW inc. from 1995 (500 kt/a)	127	0.2%	$440.28
LAND15b	MSW inc. from 1995 (500 kt/a)	21	0.0%	$379.01
LAND16	Hhd compost. from 1995	1 038	1.6%	($12.78)
LAND18a	Wet/dry from 1995	214	0.3%	$0.42
LAND18b	Wet/dry from 1995	1 716	2.6%	$0.42
LFG10	LF CH4 flaring (500 000 t/a)	252	0.4%	$0.09
LFG11	LF CH4 recovery (2500 t/a)	3	0.0%	$36.50
LFG12	LF CH4 recovery (5000 t/a)	28	0.0%	$5.45
LFG13	LF CH4 recovery (10000 t/a)	26	0.0%	$5.05
LFG14	LF CH4 recovery (25 000 t/a)	70	0.1%	$4.31
LFG15	LF CH4 recovery (50 000 t/a)	118	0.2%	$1.62
LFG16	LF CH4 recovery (100 000 t/a)	276	0.4%	($8.05)
LFG17	LF CH4 recovery (150 000 t/a)	659	1.0%	($8.07)
LFG19	LF CH4 recovery (500 000 t/a)	2 927	4.5%	($8.44)
LFG2	LF CH4 flaring (2500 t/a)	3	0.0%	$62.61
LFG3	LF CH4 flaring (5000 t/a)	22	0.0%	$17.68
LFG4	LF CH4 flaring (10000 t/a)	21	0.0%	$35.63
LFG5	LF CH4 flaring (25 000 t/a)	70	0.1%	$34.35
LFG6	LF CH4 flaring (50 000 t/a)	29	0.0%	$27.69
LFG8	LF CH4 flaring (150 000 t/a)	45	0.1%	$9.49
Sub-total for waste actions		**7 896**	**12.2%**	**$12.42**
CONC1	Concrete manufacturing	1 954	3.0%	$0.00
LIVE1	Livestock rBST	35	0.1%	($0.03)
LIVE3	Livestock biogas & protein	2	0.0%	$0.55
LIVE4	Human diet change	2	0.0%	$404.04
NG1	Blowdown gas recovery	0	0.0%	$357.88
Sub-total for other actions		**1 992**	**3.1%**	**$0.36**
Total for all actions		**64 894**	**100.0%**	**$20.92**

NOTES: Action code refers to the coding of Action Information Summary Sheets in Appendix A.
All costs and quantities are for reductions of carbon dioxide equivalent (CE) emissions in 2005 (1990$). All costs rounded to 2 decimal points.

Table 16 Actions ordered by economic attractiveness

Action Code	Description	Incremental reduction (kt-CE/a)	Cumulative reduction (kt-CE/a)	Incremental unit cost ($/t-CE)	Average unit cost ($/t-CE)	Cumulative cost (M$/a)
LAND16	Hhd compost. from 1995 (except large landfills recovering gas for energy)	1 038	1 038	($12.78)	($12.78)	($13.27)
LFG19	LF CH_4 recovery (500 000 t/a)	2 927	3 965	($8.44)	($9.58)	($38.0)
LFG17	LF CH_4 recovery (150 000 t/a)	659	4 624	($8.07)	($9.36)	($43.3)
LFG16	LF CH_4 recovery (100 000 t/a)	276	4 900	($8.05)	($9.29)	($45.5)
LIVE1	Livestock rBST	35	4 935	($0.03)	($9.22)	($45.5)
RIGID3	Rigid foams-reduction	2 832	7 766	$0.00	($5.86)	($45.5)
RIGID2	Rigid foams-reduction	2 261	10 027	$0.00	($4.54)	($45.5)
CONC1	Concrete manufacturing	1 954	11 981	$0.00	($3.80)	($45.5)
FLEX3	Flexible foam-reduction	1 358	13 339	$0.00	($3.41)	($45.5)
RIGID1	Rigid foams-reduction	567	13 906	$0.00	($3.27)	($45.5)
FLEX2	Flexible foams-reduction	81	13 986	$0.00	($3.25)	($45.5)
RIGID6	Rigid foams-chem sub	11 041	25 027	$0.00	($1.82)	($45.5)
FLEX1	Flexible foams-sub	1 977	27 004	$0.01	($1.68)	($45.5)
LFG10	LF CH_4 flaring (500 000 t/a)	252	27 257	$0.09	($1.67)	($45.5)
LAND18b	Wet/dry from 1995	1 716	28 972	$0.42	($1.54)	($44.7)
LAND18a	Wet/dry from 1995	214	29 187	$0.42	($1.53)	($44.6)
LIVE3	Livestock biogas & protein	2	29 189	$0.55	($1.53)	($44.6)
LFG15	LF CH_4 recovery (50 000 t/a)	118	29 307	$1.62	($1.52)	($44.4)
LFG14	LF CH_4 recovery (25 000 t/a)	70	29 377	$4.31	($1.50)	($44.1)
LFG13	LF CH_4 recovery (10000 t/a)	26	29 403	$5.05	($1.50)	($44.0)
LFG12	LF CH_4 recovery (5000 t/a)	28	29 430	$5.45	($1.49)	($43.9)
MOBILE5	Mobile air conditioners-wrecks	2 533	31 963	$8.64	($0.69)	($22.0)
LFG8	LF CH_4 flaring (150 000 t/a)	45	32 008	$9.49	($0.67)	($21.5)
LFG3	LF CH_4 flaring (5000 t/a)	22	32 030	$17.68	($0.66)	($21.2)
MOBILE6	Mobile air conditioners-red	10 738	42 769	$19.23	$4.33	$185.4
LFG6	LF CH_4 flaring (50 000 t/a)	29	42 798	$27.69	$4.35	$186.2
MOBILE3	Mobile air conditioners-new	1 293	44 091	$28.30	$5.05	$222.8
MOBILE2	Mobile air conditioners-new	5 112	49 203	$33.71	$8.03	$395.1
LFG5	LF CH_4 flaring (25 000 t/a)	70	49 273	$34.35	$8.07	$397.5
LFG4	LF CH_4 flaring (10000 t/a)	21	49 294	$35.63	$8.08	$398.3
LFG11	LF CH_4 recovery (2500 t/a)	3	49 297	$36.50	$8.08	$398.4
MOBILE4	Mobile air conditioners-retro	9 443	58 739	$47.57	$14.43	$847.6
LFG2	LF CH_4 flaring (2500 t/a)	3	58 742	$62.61	$14.43	$847.8
MOBILE1	Mobile air conditioners-new	5 771	64 513	$64.53	$18.91	$1 220.2
LAND13c	MSW inc. from 2004 (100 kt/a)	173	64 686	$260.31	$19.56	$1 265.1
NG1	Blowdown gas recovery	0	64 686	$357.88	$19.56	$1 265.2
LAND13b	MSW inc. from 2004 (100 kt/a)	17	64 703	$378.33	$19.65	$1 271.6
LAND15b	MSW inc. from 1995 (500 kt/a)	21	64 724	$379.01	$19.77	$1 279.7
LIVE4	Human diet change	2	64 726	$404.04	$19.78	$1 280.4
LAND15a	MSW inc. from 1995 (500 kt/a)	127	64 853	$440.28	$20.61	$1 336.4
LAND13a	MSW inc. from 2004 (100 kt/a)	41	64 894	$517.32	$20.92	$1 357.8

NOTES: Action code refers to the coding of Action Information Summary Sheets in Appendix A.
All costs and quantities are for reductions of emissions in 2005 (1990$).
All costs rounded to 2 decimal points.

In fact, as indicated in Table 16, household composters are the most attractive in all communities where landfill gas recovery cannot be done, or where landfills have a capacity below 100 000 t/a. In communities with larger landfills where the energy can be recovered, landfill gas recovery is the most attractive means of reducing emissions.

7.1.3 An abatement cost curve for actions

The abatement cost curve is estimated by plotting and sorting the incremental unit costs of actions against the cumulative carbon dioxide equivalent reduction in GHG emissions. For example, in Table 16 action LIVE1 (livestock rBST) is more attractive than action CONC1 (concrete manufacturing) for reducing carbon dioxide equivalent GHG emissions since its incremental unit cost is less (LIVE1 costs \$-0.03/t-CE versus CONC1 \$0.00/t-CE).

The actions ordered by their economic attractiveness for reducing CE emissions from least to most expensive are presented in Table 16. Ranking is based on the incremental unit cost of each action. Household composting implemented in 1995 is the most economically attractive action. Of the five actions which result in a negative cost (a net benefit) four affect waste-related activity (household composting and CH_4 recovery from landfill). These five actions result in a cumulative reduction of 4 935 t-CE/a.

The largest incremental reductions in emissions result from actions affecting emissions of CFCs, particularly through substitution actions, for rigid foam manufacturing and mobile air conditioners. Actions affecting rigid foam manufacturing are expected to be free (incremental unit cost of \$0.00/t-CE) whereas actions affecting mobile air conditioners are more expensive varying between about \$9/t-CE and \$63/t-CE.

The average unit cost, including all of the actions in Table 16 is \$20.92/t-CE. This results in a reduction in GHG emissions of about 64 900 t-CE/a. The estimated cumulative cost of these actions is an estimated \$1.4 billion. More than 32 000 t-CE could be reduced with no net cost and with significant savings (\$21 million).

Figure 2 presents the data in Table 16 graphically. Figure 3 presents the same data with CFCs excluded, indicating that if CFCs do not contribute significantly to global warming, the potential reductions of emissions are considerably lower, but most of these reductions can be achieved at no cost.[12]

[12] Note that the x-axes are different for Figure 2 and Figure 3.

7.2 Measures to induce the actions

Some of the actions are already being taken on the basis of current policies and economics. There are additional opportunities to increase the performance of these actions, and thus further reduce GHG emissions from non-energy sources, by adopting new measures.

In this section, the importance of assessing *measures* (as distinct from *actions*) is considered, and criteria for evaluating measures are considered. Finally, consideration is given to how plotting measures might affect the abatement cost curve in Figure 2.

7.2.1 The need for measures

There are two major barriers to the performance of actions to reduce emissions:

- Those responsible for a particular emissions source recognize that there are abatement actions that they could take for which there are net benefits to *society as a whole*, but they refrain from taking these actions because the benefits to *them only* are less than the costs they would incur (i.e. in economic terms, an "externality" exists).

- Those responsible for a particular emissions source are unaware that there are abatement actions that they could take for which the benefits exceed the costs, even when viewed from their private perspective (i.e. there exists a lack of information or knowledge regarding possible abatement actions).

In practice, there may be a combination of these factors inhibiting the performance of actions. This suggests three different types of policy instruments to overcome these barriers. Policy instruments to address these barriers include:

- regulations, to *require* the performance (or avoidance) of particular actions by command and control of government;

- economic instruments (such as taxes, subsidies or tradeable emissions allowances) to provide incentives for actions to be taken; and

- information measures, where government undertakes or sponsors the production and dissemination of information to promote awareness of cost-effective abatement actions.

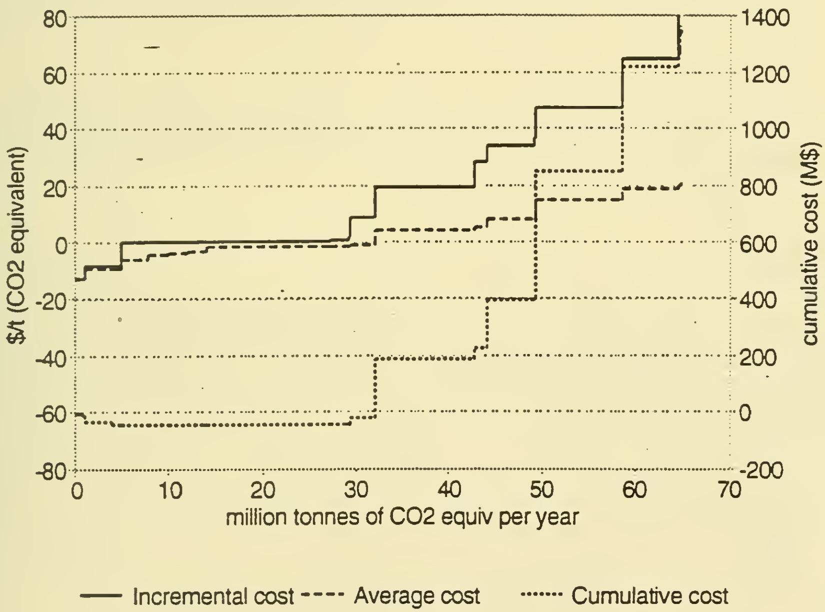

Figure 2 Average and incremental costs of achieving reductions in non-energy greenhouse gas emissions.

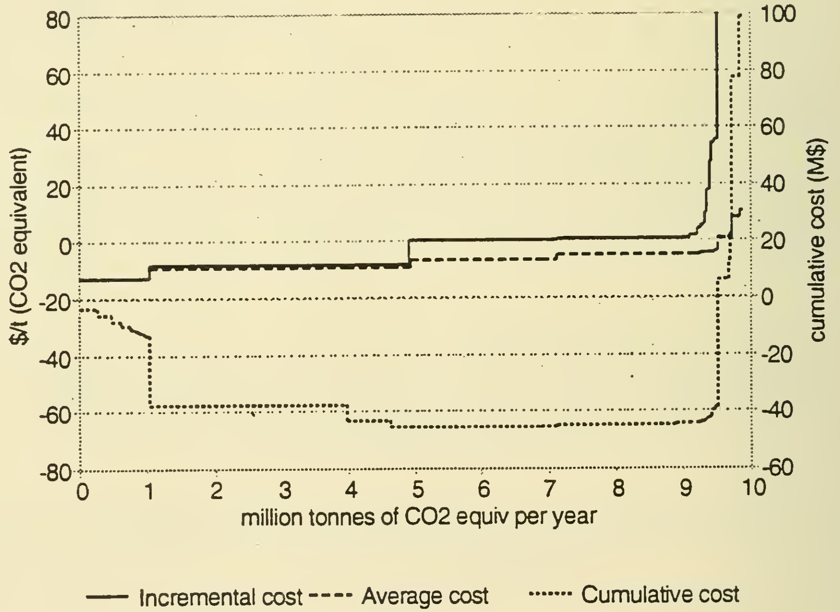

Figure 3 Average and incremental costs of achieving reductions in non-energy greenhouse gas emissions (excluding CFCs).

Where both externalities and lack of information inhibit action, measures employing combinations of policy instruments may be needed.

7.2.2 Criteria for evaluating measures

The appropriateness of new environmental policy measures must usually be assessed against several criteria. One such set of criteria is outlined in Table 17. These are broadly consistent with other lists of criteria for evaluating measures (see, e.g., OECD 1991).

First, there is administrative feasibility, which is a part of a broader criterion of applicability, including the level of jurisdiction that can apply the measure (i.e. whether the measure is within federal, provincial or provincial/municipal jurisdiction).

Second there is effectiveness of the measure in achieving an environmental target.

Third, based on the total costs of a measure, including its administrative costs as well as the costs of the action that it induces, the efficiency of the measure is assessed. Since the administrative costs of measures will be different, the order of measures in terms of cost may be different from the order of actions. For example, the costs of mandating landfill gas recovery are minimal but the costs of training and implementation for home composting are high. As such, when a measure's cost is added to the action costs the total costs will not only increase but may also affect the order of actions. Therefore, the abatement cost curve for measures will have higher costs, and could have a different order of actions than the abatement cost curve for actions. Nevertheless, it is the abatement cost curve for measures rather than actions that is relevant in assessing a measure on the basis of efficiency from a policy maker's perspective.

Finally, we consider acceptability as part of a broader criterion of equity, because where acceptability is challenged it is usually based on some consideration of equity. Also, we consider acceptability in relation to effectiveness and efficiency, because acceptability is likely to affect the level and costs of compliance. The Polluter Pays Principle (OECD 1975), which the OECD has recommended on the basis both of efficiency and equity, is also applied here as an aspect of equity. The Polluter Pays Principle states that polluters should be responsible for meeting environmental

standards and any costs that they incur in doing so; polluters should not be subsidized to meet environmental standards.

Table 17 Summary of criteria for the evaluation of measures

Applicability	jurisdiction administrative means ease of monitoring performance independently adoptable
Effectiveness	potential reduction (t-CE) potential reduction (%targets) response capacity enforceable
Efficiency	administrative costs static net cost/t-CE static separable cost/t-CE dynamic efficiency
Equity	polluter pays principle distribution relative to status quo allocation of joint costs/benefits equal costs per unit of contribution to global warming

There is a large number of measures that are potentially applicable to each source and action, including economic instruments and information measures, as well as regulations. It is impractical or very costly to monitor GHG emissions directly. Therefore, policy measures to control GHG emissions directly are usually inapplicable.

As such it may also be necessary to base policies on proxy factors (control factors which effect the level of GHG emissions) that are indicative of GHG emissions. The rate or quantity of emissions from an anthropogenic process will depend on the following control factors:

- the types and quantities of *inputs and outputs*;
- the *technology* that is used;
- the manner of *operation* of the technology; and

- the *situation* in which the operation occurs.

These control factors of GHG emissions yield a range of possible policy instruments that are intended to limit or restrict GHG emissions (Table 18).

Table 18 Types of measures applicable by control factors

Control factor	Economic instruments	Regulatory measures	Information measures
Emissions	charges (per unit) tradeable permits non-compliance fees performance bonds	limits	
Inputs/Outputs	charges added to price deposit-refund system	restrictions on type restrictions on uses sunsetting uses	promote alternatives product labelling R&D: new products
Technology	charges subsidies tax differentiation	standards sunsetting technologies	promote alternatives product labelling R&D: new technologies
Operation	tax differentiation non-compliance fees performance bonds	operating requirements	augment training research
Situation	tax differentiation non-compliance fees performance bonds	restrictions	augment training research

Given the extensive range of possible measures for each source, it is desirable to specify and assess these measures qualitatively according to the evaluation criteria (Table 17). This will reduce the number of measures considered in more detailed to a few for each source. The advantage of this approach is that rather than undertaking a detailed evaluation of all measures only the most promising for each emission source are evaluated.

7.2.3 An abatement cost curve for measures

The ultimate aim should be to produce an abatement cost curve for measures, as has been done for actions. The full cost of achieving the reductions includes both the costs of the technology, and the costs of implementing and administering the measure to induce its adoption. As noted above, the ordering of economic attractiveness of individual actions may differ when the costs of measures is included since some actions will require measures that are more difficult and expensive to implement than others.

To this end, it is necessary to consider the component costs for administering some of the measures. In some cases, it may be possible to say whether the administrative costs of a measure are likely to be "large" or "small" *relative to* the costs of the actions to comply with the measures. Based on the availability of this information a provisional least-cost abatement curve for measures may be constructed from the abatement cost curve for actions by temporarily taking out the actions for which administrative costs are relatively large, until the costs of these measures (including administrative costs) can be determined more precisely.

Administrative costs are likely to be greatest for those measures that apply to a large number of establishments (households, farms). Administrative costs will usually be relatively small for industries (including landfills, wrecking yards, etc.), especially those with a small number of firms; this is the case for most of the actions. The acceptability of measures is also likely to be greater in these latter cases.

8 Impact analysis of actions

Until recently, government planning and policy formulation and evaluation have relied heavily on intuition and assumption rather than on empirical assessment. Today, environmental policy is under pressure to increase its capacity to utilize information and expertise in the planning and evaluation processes.

As economic resources are becoming scarcer, competition for dwindling resources has created the necessity for rationalizing the use of these scarce resources and public funds as never before. In this respect social and general indicators are no longer sufficient. Equally important is the use of economic methods and techniques to evaluate the economic worth and impact of activities on the provincial economy and on several recognized economic and social indicators.

In this chapter the *impacts* of actions mitigating non-energy greenhouse gas emissions are estimated using an input-output model. The actions considered are for the most significant sources of non-energy greenhouse gas emissions: CFCs for refrigeration and air conditioning, plastic foam production for insulation and methane gases from landfills, as presented in Table 16.

The actions considered use scarce resources, alter the economic structures of original operations and change the commodity composition of outputs and inputs of what would have existed in the absence of any mitigating action. This change in the pattern of resource use and the nature of the action taken to reduce non-energy GHG emissions determines the magnitude and nature of the economic consequences of these actions. Some of these impacts, particularly those actions requiring large capital and operating expenditures, may result in positive impacts in the sense that they involve new expenditures on goods and services within the province and could, as such, be considered as employment sustaining.

However, some of the actions considered in this study involve re-arranging the emissions so as to permit the re-utilization of the emissions in productive activity (i.e. recovery of landfill methane). The impact of these actions on economy may be negative. This occurs if the operating and capital costs needed to sustain the collection and re-utilization of the captured emissions is lower than the use of alternative inputs whose use is placed in jeopardy.

This chapter outlines the type of impacts estimated using the input-output model and presents the results of this analysis for actions reducing non-energy GHG emissions.

8.1 Description of impact analysis

Economic impact analysis is predicated on two fundamental principles:

- Regardless of the primary function and worth of any action or activity in society, to the extent that its implementation involves the use of economic resources, society derives an economic impact from it that is particularly dependent on its level of operation and pattern of resource use.

- Economic impacts are only partially measured using the initial expenditures on the action. A more complete and accurate picture of impacts emerges from adding the indirect and induced effects to the initial effects.

The secondary effects (indirect and induced) arise because the economy is a complex system of interacting sectors that are tightly linked to one another. For example, expenditures by firms on machinery call for a large array of supporting supplies from other sectors that are not intuitively associated with machinery production. Expenses on machinery will increase the demand for cement, steel, other machinery, furniture and so on which, in turn, generates demand for labour, energy, etc. These impacts are generally referred to as the indirect effects of the original expenditures on machinery. But as production increases, incomes of factors of production also increase, triggering in turn additional expenditures on consumer goods. The latter impacts are generally referred to as the induced effects. The sum total of direct, indirect and induced effects represent the total impact of the original expenditures on the economy. These three component effects are captured using an input/output model. The use of these models to capture all the rounds of impacts is now a standard practice in impact analysis.

Economic impacts may be measured from either the demand side or the supply side. The demand side is deemed more appropriate in cases where consumer demand and choices prevail. In the analysis of investment projects and mitigative activities such as those considered in this study, the supply side is more relevant. Expenditures associated with mitigating actions are broken down into their commodity composition (inputs into production) and the latter allocated to the appropriate final demand category. A full input/output solution is generated driven by the specified final demand.

Different indicators can be used to gauge the magnitude and direction of the impacts of changes in economic activity. The most relevant and commonly used economic indicator is that of **employment** sustained by the action. Employment impacts are the person-years of employment created as a result of the action and are relevant here inasmuch as some of the actions may be expected to result in negative impacts.

In addition to employment, **value added** (income) which represents the sum total of factor payments made in the course of implementing the action is calculated. Value added may not correspond directly to employment. Some actions may have high employment but modest value added impacts. Another indicator of impact is **gross output** (shipments or sales). This is a valuable indicator of overall activity in an economy to businesses which are concerned about their turnover and volume of sales. **Labour income** is an indicator of the income received through employment resulting from the implementation of each action.

The ability of government to introduce measures that lead to the implementation of these actions depends on its ability to fund them. As such an indicator regarding **tax revenues** by level of government also is used. The level of tax revenue arising from an action provides some information about the likely revenues government can expect from implementing an action. Tax revenues are also determined by a number of economic variables that include wages and salaries, other income, sales, etc.

All of the economic activity indicators used in this study are presented in terms of their direct (initial), indirect and induced effects. Multipliers associated with each action and economic impact indicator are calculated for comparative purposes. Generally, multipliers are calculated by dividing total economic effect by original expenditures. The employment multiplier is calculated by dividing total employment by direct employment to determine the multiplier.

Impact analysis is only one method of many to analyze the economic consequences of actions to reduce greenhouse gases from non-energy sources. Cost benefit analysis could also be used to evaluate the total social costs and benefits of the actions. In addition, a management or financial accounting approach could be used to examine the total revenues and expenditures resulting from each action. From the perspective of impact analysis, given its heavy emphasis on maintaining jobs, the creation of new sources of energy could be considered a drawback, particularly if it were to reduce the jobs in the community. For example, the recycling of methane which saves on energy requirements for heating and production cannot be considered as having totally negative impacts.

The impact analysis undertaken in this study does not utilize a multiple accounting framework of the social worth of different actions and activities which delineates the

perimeters of trade-offs involved between economic and environmental objectives. Rather it provides only information on secondary economic consequences associated with direct expenditures on actions.

8.2 Economic impact of actions

A number of actions are identified as attractive for reducing non-energy greenhouse gas emissions (Table 16).

Some emissions sources had more than one economically attractive action. In such instances it was necessary to assess how these actions interact with one another. This was done by considering actions that apply to a single source together, and then estimating the cost of moving from the least expensive to the most expensive action on an incremental basis. Based on this analysis, it was possible to eliminate some actions and combine others. These involved higher costs and result in small reductions in emissions than at least one other action that applies to the same emissions source. Thus, household composters are very attractive in all communities where landfill gas recovery cannot be done, or where landfill capacity is below 100 000 t/a. On the other hand, in large communities with large landfill capacities where it is possible to recover methane, this recovery is the most efficient means for reducing emissions. A more detailed description of the selection of economically attractive actions is provided in Appendix B.

Each action considered in the study was assigned a capital cost and a stream of operating costs. The latter were discounted and their present value estimated in 1990 dollars (Appendix A). To the extent that an action involves capital or operating costs or both with no compensating revenues, these costs were allocated to the commodities sustaining the expenditure. It is these expenditures which are fed separately for each action through the input/output model to generate the results shown in Table 19 and Table 20.

If an action resulted in displacing another commodity input or generated its own source of energy (eg. landfill methane), the revenues from these commodity inputs were deducted from the initial capital and operating expenditures to arrive at what is termed as net impacts. For example, the capital and operating expenditures to purchase a set of commodity inputs to recover landfill methane results in a commodity output (energy). The use of this output as a commodity input elsewhere in the economy is a flow of revenue to the initial action. It is this flow of revenue which is deducted from the initial capital and operating expenditures.

In one case there were reductions in inputs with no or little increase in operating or capital expenditures. This is the case of CONC1, in which cement use was reduced by 25 per cent. The economic level of construction in Ontario in 1990 was used to assume the final demand for concrete, but with a technological change that reduces the use of cement by 25 per cent. Naturally, the results showed a major decline in the number of jobs and income. The results under the column heading of Concrete are therefore negative.

The result of eliminating non-cost effective actions and combining actions affecting common sources results in 14 separate groupings of 24 actions included in the impact analysis.

8.3 Results of impact analysis

The action to reduce non-energy sources of GHG emissions were evaluated based on the following:

- total provincial impacts;
- impacts by industrial sector; and
- relative (comparative) impacts between actions.

Each action was analysed separately in the input-output model.

8.3.1 Provincial impacts

Based on a total initial expenditure just under $5 billion, the estimated total net provincial impact of all the actions considered is about 122 thousand new person-years of employment and over $7 billion in value added income (Table 19). The economic impact on provincical gross output is expected to increase by about $12 billion while total labour income increases by about $5 billion (Table 19). Government tax revenue is expected to increase by about $2 billion with federal authorities receiving almost two-thirds of the increased revenue.

Mobile actions (MOBILE1 and MOBILE4) show the highest impacts since they result in very large capital and operating expenditures. Together these two actions result in over 60% of the net employment and value added impacts. It is not hard to believe that these impacts may be additional to the overall economic performance of Ontario. Together they call for a net initial expenditure of about $3 billion (Table 19). This amount is not expected to be made in one or two years. Rather it is expected to be spread over a long period. The $3 billion is the present value of a stream of expenditures over a period of years depending on the action (eg. from 1 year for MOBILE4 to 10 years for MOBILE1). A complete description of the length of time from implementing the action to 2005 is provided in Appendix A.

It is possible, therefore, that the economy will be able to absorb the impact of these actions without any crowding out of other activities given the low inflationary pressures and the state of generalized excess capacity of the current and medium term outlook of the Ontario economy.

Only one action results in a negative net economic impact, CONCRETE1. This is not unexpected since the assumption used to estimate these impacts assumes cement use was reduced by 25%, adversely affecting the final demand for construction services.

8.3.2 Sectoral employment impacts

It is to be expected that a different sectoral profile of the economic impact is likely to emerge in association with each action. These impacts on 25 different industrial sectors are presented in Table 20.

The largest employment impacts occur in the services and government, machinery and trade sectors where just under one-half of all new person years of employment were created. The major actions contributing to the gain in employment are MOBILE1 and MOBILE4. These actions require significant new purchases of installation and servicing equipment as well as regular inspection and maintenance of motor vehicles.

The LFG actions contribute only marginally to sectoral employment since these actions create a flow of revenue through the sale of energy, offsetting the employment gains from the initial capital expenditures.[13]

[13] FLEX1 which results in the least provincial impact is excluded from the sectoral analysis since its sectoral impact is negligible (less than 0.5 person years of employment for any single sector.

Several conclusions can be reached based on the sectoral analysis. First, the utility sector is seen to lose jobs as landfill gases (LFG) are gathered and used. Second, under composting actions (LAND16) it seems that plastic production (other manufacturing) is significantly increased as plastic composters are used whereas the other landfil diversion LAND actions result in a significant increase in the machinery and services and government sectors. Third, a selected set of sectors are impacted more than others for most actions. These include machinery, services & government, utilities, metals, plastic (other manufacturing) and trade. This is the result of a change in final demand arising from the indirect and induced impacts of the actions.

The results of the sectoral impact analysis exclude the CONC1 action since the assumption to determine the impact of this action is based on the reduction of the final demand for construction services. The reduction in final demand impacts different industrial sectors but does not make explicit the relationship between sectoral impacts and the action (CONC1).

8.3.3 Comparative ranking of the impact of actions

Since the economic impact results vary by sector as well as by indicator for each action, it would be useful to narrow down the basis of comparing actions by adopting a common base (denominator) for all the actions as was done for the ranking of economic attractiveness where t-CE was used a a denominator (Table 16). Such a comparison, or ranking, of the impacts of actions provides a more comprehensive picture of the relative impact of each action.

Two possible ranking schemes were considered. Firstly, to rank each action in terms of its impact resulting from the same amount of dollar expenditures to initiate the action. That is, all impacts arise from the same common level of expenditures per action. Secondly, to rank the impacts of actions based on the same level of reduction in GHG emissions (the same quantity reduction in GHG is imposed on all actions). This second method, resulting in a different level of expenditure per action to attain the same reduction in GHG, is used in this study for standardizing the impacts of the actions.

For example, consider the fact that household composting in smaller communities (LAND16) involves the net initial expenditure of about $200 million (Table 19). Alternatively, large scale landfill gas recovery (LFG16, LFG17 and LFG19) involves the expenditure of about $210 million. It is not legitimate to compare these two actions without reducing them to the same denominator. All that is required is either

to reduce gas recovery expenditures proportionately to $200 from $210 or to raise household composting to $210 from $196. In either case it is clear that landfill gas recovery is more efficient as it results in higher income and employment impacts for the same level of dollars (Table 19). The same standardizing procedure may be applied to all the actions. It is only after this standardization procedure that a true comparison can be made. Such a comparison permits an assessment of the trade-offs implicit in choosing any one action rather than another.

Three economic indicators were used to rank the impact of actions:

- According to their income (value added) contributions (this ranking resulted in a similar ranking to gross output and labour income).
- According to the total number of person-years of employment they sustain.
- By the income multiplier associated with the different actions. This ranking focuses on the efficiency of the action to generate income per unit of expenditure (cost). It is independent of the size of the impact.

In Table 16, actions are listed in descending order of their incremental costs ($/t-CE) of emissions reduction. Because these actions use scarce resources and some even generate revenues, they result in a stream of economic consequences on the economy at large. The economic streams may not be in one-to-one correspondence with their economic attractiveness rankings in Table 16. This being the case, it is possible to define the terms of trade offs in economic activity between actions as shown in Table 19.

The relative comparison of the impacts of each action provide some interesting results. Firstly, while the large scale landfill gas recovery action (LFG16, LFG17 and LFG19) assumes the top position under the income generated per one dollar of expenditure, it ranks in the middle in terms of employment generation and near the top in unit costs. As such, it, and all landfill gas actions (LFG), do not show a discernible pattern about the way these actions make their contribution to economic activity. Secondly, large scale gas flaring (LFG10) shows a relatively low income multiplier, employment generation and incremental reduction. It ranks above average only in terms of low unit cost.

Thirdly, in terms of sheer size, retrofitting mobile air conditioners (MOBILE4) makes a large contribution to incremental emission reduction and employment, but in terms of efficiency it ranks rather low (value added multiplier). All the mobile actions result in large reductions in emissions but surprisingly, only MOBILE4 and MOBILE1

result in the creation of significant amounts of employment. Invariably, all of the MOBILE actions show small value added multipliers and relatively high unit costs. Finally, LAND16, household composters, is the most efficient in terms of income per unit of GHG reduced of all of the actions.

The fact that different ordering of actions emerged under each of the different economic indicators used in Table 19 suggests that there exists a need to further assess the implicit trade-offs in the choosing one or another of these actions.

Table 19 Economic impact of actions on Ontario

Projects / Impacts (millions of 1990$)	LAND16	LFG16, 17 & 19	CON-CRETE1	FLEX1	LFG10	LAND18a, 18b	LFG12, 13, 14 & 15	MOBILE5	MOBILE6	LFG4, 5 & 6	MOBILE1	MOBILE4	LAND13a & 13b	LAND15a & 15b	Total
Net initial expenditures	$196.2	$210.9	($243.8)	$0.3	$4.4	$240.1	$48.0	$20.6	$209.0	$11.2	$818.6	$2 128.9	$615.1	$447.3	$4 706.8
Gross output															
Direct	$196.2	$210.9	($243.8)	$0.3	$4.4	$240.1	$48.0	$20.6	$209.0	$11.2	$818.6	$2 128.9	$615.1	$447.3	$4 706.8
Indirect & induced	$296.2	$324.5	($354.9)	$0.4	$6.4	$351.3	$72.7	$32.2	$346.9	$16.3	$1 194.2	$3 145.8	$889.8	$647.1	$6 968.9
Total	$492.4	$535.4	($598.7)	$0.7	$10.8	$591.4	$120.7	$52.8	$555.9	$27.5	$2 012.8	$5 274.7	$1 504.9	$1 094.4	$11 675.7
Multiplier	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.6	2.7	2.5	2.5	2.5	2.4	2.4	2.5
Value added															
Direct	$88.5	$95.5	($114.6)	$0.1	$2.0	$110.8	$21.9	$7.8	$62.2	$5.2	$346.3	$921.8	$287.0	$208.8	$2 043.3
Indirect & induced	$206.5	$236.0	($261.9)	$0.3	$4.7	$255.7	$53.1	$21.2	$205.8	$12.0	$844.9	$2 230.4	$654.7	$476.2	$4 939.6
Total	$295.0	$331.5	($376.5)	$0.4	$6.7	$366.5	$75.0	$29.0	$268.0	$17.2	$1 191.2	$3 152.2	$941.7	$685.0	$6 982.9
Multiplier	1.5	1.6	1.5	1.6	1.5	1.5	1.6	1.4	1.3	1.5	1.5	1.5	1.5	1.5	1.5
Employment (person years)															
Direct	1 434.0	1 789.0	(1 868.0)	2.0	37.0	1 874.0	411.0	125.0	783.0	94.0	5 944.0	16 078.0	5 292.0	3 849.0	35 844.0
Indirect & induced	3 747.0	4 054.0	(4 627.0)	5.0	81.0	4 399.0	911.0	379.0	3 843.0	205.0	14 807.0	38 870.0	11 221.0	8 161.0	86 056.0
Total	5 181.0	5 843.0	(6 495.0)	7.0	118.0	6 273.0	1 322.0	504.0	4 626.0	299.0	20 751.0	54 948.0	16 513.0	12 010.0	121 900.0
Multiplier	3.6	3.3	3.5	3.5	3.2	3.3	3.2	4.0	5.9	3.2	3.5	3.4	3.1	3.1	3.4
Labour income															
Direct	$56.6	$65.1	($67.6)	$0.1	$1.3	$69.6	$14.7	$4.9	$37.2	$3.3	$211.7	$574.9	$180.8	$131.5	$1 284.1
Indirect & induced	$149.0	$170.7	($182.5)	$0.2	$3.4	$183.2	$38.2	$15.5	$154.6	$8.5	$598.6	$1 594.9	$366.0	$338.9	$3 439.2
Total	$205.6	$235.8	($250.1)	$0.3	$4.7	$252.8	$52.9	$20.4	$191.8	$11.8	$810.3	$2 169.8	$546.8	$470.4	$4 723.3
Taxes															
Federal	$66.0	$68.8	($61.9)	$0.1	$1.3	$71.8	$15.3	$5.5	$49.0	$3.3	$226.0	$602.7	$179.5	$130.5	$1 357.9
Provincial	$25.4	$28.4	($31.3)	$0.0	$0.6	$30.3	$6.4	$2.5	$24.3	$1.4	$100.9	$264.9	$77.3	$56.2	$587.3
Local	$5.0	$5.6	($7.1)	$0.0	$0.1	$6.0	$1.3	$0.5	$4.4	$0.3	$21.3	$53.0	$15.1	$11.0	$116.5
Total	$96.4	$102.8	($100.3)	$0.1	$2.0	$108.1	$23.0	$8.5	$77.7	$5.0	$348.2	$920.6	$271.9	$197.7	$2 061.7

NOTE: The sectoral impacts for CONCRETE1 are excluded since the impacts are based on a change in the final demand for construction services rather than a change in the commodity inputs to concrete manufacture. Non-cost effective actions and actions affecting identical sources are combined. For a description of each action and expected initial expenditures and the sources affected see Appendix B.

Table 20 Employment impacts by industry if actions on Ontario

Projects Industry (Person years employment)	LAND16	LFG16, 17 & 19	LFG10	LAND18a & 18b	LFG12, 13, 14 & 15	MOBILE5	MOBILE6	LFG4, 5 & 6	MOBILE1	MOBILE4	LAND13a, 13b & 13c	LAND15a & 15b	Total
Agriculture	75.9	77.4	1.5	80.9	17.3	6.6	62.5	3.8	397.0	835.8	208.2	151.4	1 918.3
Forestry	14.3	7.7	0.1	7.5	1.7	0.6	6.3	0.4	28.2	70.0	19.6	14.3	170.8
Fishing	0.8	0.9	0.0	1.0	0.2	0.1	0.8	0.1	3.3	8.5	2.5	1.8	19.9
Mining	32.7	4.7	0.1	7.2	1.2	0.6	5.8	0.3	34.4	73.0	19.0	13.8	192.8
Food and beverage	58.0	66.1	1.3	69.5	14.8	5.6	52.3	3.3	258.4	633.2	178.4	129.8	1 470.6
Primary textile	82.3	16.9	0.3	17.5	3.8	1.9	22.7	0.8	59.4	163.1	45.1	32.8	446.6
Knitting & weaving	45.8	32.2	0.6	34.5	7.2	2.8	26.5	1.6	110.7	296.5	88.2	64.2	710.7
Wood	8.3	6.6	0.1	7.0	1.5	0.6	6.2	0.3	22.8	61.1	17.7	12.9	145.2
Furniture	11.0	16.0	0.3	16.9	3.6	1.2	10.2	0.8	50.3	137.5	42.2	30.7	320.6
Paper	83.8	28.6	0.5	27.1	6.3	2.3	22.4	1.3	114.4	265.1	70.4	51.2	673.5
Printing	36.0	58.0	1.0	47.4	12.6	4.6	46.0	2.5	185.7	475.1	135.0	98.2	1 101.9
Primary metals	35.1	189.0	3.2	183.8	40.6	14.9	149.0	8.2	457.8	1 415.2	431.3	313.7	3 241.9
Fabricated metals	65.7	476.4	8.1	459.9	102.2	24.1	108.0	20.5	1 091.6	3 237.2	1 077.4	783.6	7 454.7
Machinery	9.4	1 455.7	24.5	1 404.4	311.8	59.3	49.4	62.4	3 199.5	9 457.4	3 266.0	2 375.2	21 674.9
Transport equipment	25.6	48.0	0.9	50.3	10.6	51.6	991.7	2.3	140.1	1 304.3	124.9	90.8	2 841.1
Electrical Products	31.6	570.1	9.7	551.7	122.3	25.0	51.5	24.6	1 280.5	3 777.5	1 290.4	938.5	8 673.3
Non-Metal	11.7	19.4	0.4	19.6	4.2	2.3	29.3	0.9	65.7	182.2	47.8	34.8	418.1
Petroleum petrochemical	14.2	8.7	0.2	12.6	2.1	1.1	10.3	0.6	88.1	156.8	33.8	24.6	353.1
Chemical Production	152.1	42.6	0.8	43.4	9.4	3.7	37.6	2.0	1 307.0	1 543.2	108.8	79.2	3 329.8
Other manufacturing	2 432.5	115.7	2.1	113.8	25.3	10.3	109.9	5.3	382.7	1 010.3	281.9	205.0	4 694.7
Construction	34.3	26.3	0.8	41.8	6.7	3.5	34.5	2.0	153.2	381.8	113.3	82.4	880.4
Utilities	342.2	(567.6)	7.7	415.6	(70.6)	36.4	370.7	19.6	1 531.3	3 834.6	1 487.2	1 081.6	8 488.7
Trade	609.5	878.9	16.2	857.8	194.3	67.4	599.1	41.2	2 849.0	7 510.9	2 237.1	1 627.0	17 488.2
Services & Government	529.1	1 762.1	27.4	1 261.0	380.1	134.1	1 413.0	69.7	5 210.2	13 485.2	3 806.7	2 768.5	30 847.1
Other employment	439.0	503.2	9.9	539.6	112.9	43.5	409.6	25.3	1 729.6	4 631.7	1 380.7	1 004.1	10 829.0
Total	5 180.6	5 843.6	117.7	6 271.6	1 322.1	503.9	4 625.2	299.7	20 750.5	54 947.3	16 513.7	12 010.0	128 385.8

NOTE: The sectoral impacts for CONCRETE1 are excluded since the impacts are based on a change in the final demand for construction services rather than a change in the commodity inputs to concrete manufacture. Non-cost effective actions and actions affecting identical sources are combined. For a description of each action and expected initial expenditures and the sources affected see Appendix B.

Table 21 Ranking of actions by value added multiplier, employment and unit cost

Ranked by value added multiplier	Ranked by employment	Ranked by unit cost
Large scale landfill gas recovery[a]	Retrofit mobile air conditioners[b]	Household composting[c]
Small scale landfill gas recovery[d]	New mobile air conditioners[e]	Large scale landfill gas recovery[a]
Substitutes for flexible foams[f]	Incineration from 2004[g]	Retrofit mobile air conditioners[b]
LF gas flaring in medium communities[h]	MSW Incineration from 1995[i]	Large scale gas flaring[j]
MSW Incineration from 1995[i]	Wet/dry from 1995[k]	Wet/dry from 1995[k]
Incineration from 2004[g]	Large scale landfill gas recovery[a]	Small scale landfill gas recovery[d]
Wet/dry from 1995[k]	Household composting[c]	CFCs from auto wrecks[l]
Large scale gas flaring[j]	Reduction in mobile ACs[m]	Reduction in mobile ACs[m]
Household composting[c]	Small scale landfill gas recovery[d]	LF gas flaring in medium communities[h]
Retrofit mobile air conditioners[b]	CFCs from auto wrecks[l]	Retrofit mobile air conditioners[b]
New mobile air conditioners[e]	LF gas flaring in medium communities[h]	New mobile air conditioners[e]
CFCs from auto wrecks[l]	Large scale gas flaring[j]	Incineration from 2004[g]
Reduction in mobile ACs[m]	Substitutes for flexible foams[f]	MSW Incineration from 1995[i]

NOTES: a. Action codes LFG16, LFG17, LFG19 (see Appendix A)
b. Action code MOBILE4
c. Action code LAND16 in smaller communities and large communities without landfill gas recovery
d. Action codes LFG12, LFG15
e. Action code MOBILE1
f. Action code FLEX1
g. Action code LAND16
h. Action codes LFG4, LFG5, LFG6
i. Action code LFG15
j. Action code LFG10
k. Action code LFG18a, LFG18b
l. Action code MOBILE5
m. Action code MOBILE6

9 Conclusions and recommendations

The major sources of non-energy greenhouse gas emissions, and the major areas where reductions are possible, are CFCs used for foam blowing agents and for refrigerants. Methane emitted from landfills is the largest non-CFC source.

There are a range of actions possible for reducing emissions, some related to reducing the demand for the product; others relate to finding substitute products. Assessing which of these is most attractive requires consideration of the quantities of gas affected, the cost of the action, the global warming potential of affected gases (including substitutes), and the costs of other actions for the same source. Implementation date is also important for some sources, since releases occur considerably after the decision is made to use a particular CFC or to landfill waste. Many of the actions considered in this study to eliminate the use of CFCs as foam blowing agents and for refrigerants are consistent with the proposed bans and phase-outs recommended by the *Montreal Protocal* and adopted by the federal and Ontario governments.

The methodology presented in the report allows all these factors to be assessed, and suggests an ordering of actions based on costs. To achieve emission reductions in 2005, some actions ought to be taken soon, but others can be deferred until near 2005. However, deferring actions will not reduce emissions today. Almost a third of the anticipated emissions reductions can be achieved at zero or negative cost, and many of these actions are likely to be taken to accrue other benefits such as lower operating costs. On average, more than half the emissions reductions can be achieved at zero cost. Consequently, there will be minimal cost associated with achieving significant reductions in non-energy related sources of greenhouse gases.

Appendix A Action summary information sheets

Actions available to reduce non-energy greenhouse gas emissions, discussed in Chapters 3 through 6, are summarized in the following *Action Summary Information Sheets*.

Most fields included in the summary information sheets are self-explanatory. Where the SOURCE AFFECTED is, for example, concrete manufacturing, the QUANTITY OF SOURCE is expressed in units of concrete manufacturers (such as that summarized in action code CONC1). GREENHOUSE GAS QUANTITY reductions are expressed in natural units (t/a) for the number of units (sources) identified. This total potential quantity reduced is multiplied by expected LEVEL OF EFFECTIVENESS to yield estimated EFFECT ON GREENHOUSE GASES. CAPITAL COST OF ACTION and OPERATING COST OF ACTION, together with LIFETIME, IMPLEMENTATION SCHEDULE and PRIVATE AND SOCIAL DISCOUNT RATE, combine to produce TOTAL NET COST OF ACTION per year (1990$/a).

Action summary information sheet					
Sources affected	Concrete manufacturing			Action code Conc1	
Action	Reduction				
Type of action	Reduce amount of portland cement by 25 per cent				
Description	Use slag, fly ash or bottom ash instead of Portland cement in the manufacture of concrete.				
Comments	Slag, fly ash or bottom ash has been used in concrete manufacture for over 100 years. For most concrete uses fly ash is a viable alternative. May not be appropriate where strength of concrete is a priority. Can replace between 25 and 70 of required raw materials (e.g., lime, silica).				
References	OTA 1990; ACI 1987; PCA 1989.				
Greenhouse gases	CO_2				
Indirect impacts	Reduction of waste to landfill; reduced energy use in the manufacture of cement.				
Quantity of source	7	Portland cement producers			
Greenhouse gas quantity	na	per unit (kg/a)		7 814 000	Total (t/a)
Capital cost of action	$0	(1990$)/unit			
Operating cost of action	$0	(1990$)/unit/a			
Operating benefits	n/a				
Lifetime of action	25	year			
Delay in reduction	0	year			
Level of effectiveness	25.0%				
Implementation schedule	2005				
Effect on greenhouse gases	Reduction (t/a)				
	CO_2				
	1953500				
Total net cost of action	Capital cost (1990$)	Operating cost (1990$/a)	Operating benefits (1990$/a)	Annual net cost (1990$/a)	
	$0	$0	$0	$0	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet					
Sources affected	Flexible foams		Action code Flex1		
Action	Chemical substitution				
Type of action	HCFC-123				
Description	Flexible polyurethane slabstock and moulded foam used for cushioning.				
Comments	Auxiliary blowing agent HCFC-123 has 0.02 the GWP of CFC-11. Undergoing toxicity testing. Concerns regarding health and safety in the workplace.				
References	Bach and Jain 1990; Environment Canada 1989; Stevenson Kellogg Ernst & Young 1989; Jeffs, Rosebotham and Thomas 1990; Jeffs and Sparrow 1990; Cunningham, Rosebotham and Sparrow 1990; Lashof and Tirpak 1990.				
Greenhouse gases	CFC-11				
Indirect impacts	Reduces ODP.				
Quantity of source	9	producers			
Greenhouse gas quantity	na	per unit (kg/a)		579	Total (t/a)
Capital cost of action	$275 000	(1990$)/unit			
Operating cost of action	na	(1990$)/unit/a			
Operating benefits	n/a				
Lifetime of action	20	years			
Delay in reduction	1	years			
Level of effectiveness	100%				
Implementation schedule	2004				
Effect on greenhouse gases	Reduction (t/a)				
	CFC-11	HCFC-123			
	579	(579)			
Total net cost of action	Capital cost (1990$)	Operating cost (1990$/a)	Operating benefits (1990$/a)	Annual net cost (1990$/a)	
	$275 000	na	$0	$25 414	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet					
Sources affected	Flexible foams		Action code Flex2		
Action	Reduction				
Type of action	Better management practices/housekeeping during production process of flexible polyurethane foams.				
Description	Decrease use of isocyanate in manufacturing process, decreasing the need for CFCs as softeners.				
Comments	Flexible foam used for padding in furniture, carpet underlay and motor vehicle seats. Manufacturers can reduce isocyanate use immediately. Operating cost saving in isocyanate and CFCs used. Avoid using CFC for flushing/cleaning system.				
References	UNEP 1991.				
Greenhouse gases	CFC-11				
Indirect impacts	None.				
Quantity of source	9	producers			
Greenhouse gas quantity	na	per unit (kg/a)		579	Total (t/a)
Capital cost of action	$0	(1990$)/unit			
Operating cost of action	$0	(1990$)/unit/a			
Operating benefits	n/a				
Lifetime of action	20	years			
Delay in reduction	1	years			
Level of effectiveness	67%				
Implementation schedule	2004				
Effect on greenhouse gases	Reduction (t/a)				
	CFC-11				
	388				
Total net cost of action	Capital cost (1990$)	Operating cost (1990$/a)	Operating benefits (1990$/a)	Annual net cost (1990$/a)	
	$0	$0	$0	$0	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet					
Sources affected	Flexible foams			Action code Flex3	
Action	Product substitutes				
Type of action	Alternative cushioning.				
Description	Use currently available materials such as rubber and synthetic fibrefill instead of CFC.				
Comments	Applicable to furniture and bedding uses of slabstock.				
References	UNEP 1991; Stevenson Kellogg Ernst & Young 1990.				
Greenhouse gases	CFC-11				
Indirect impacts	Eliminates ODP. Reduces stock of natural resources.				
Quantity of source	na	tonnes			
Greenhouse gas quantity	na	per unit (kg/a)		579	Total (t/a)
Capital cost of action	$0	(1990$)/unit			
Operating cost of action	$0	(1990$)/unit/a			
Operating benefits	n/a				
Lifetime of action	20	years			
Delay in reduction	1	years			
Level of effectiveness	4%				
Implementation schedule	2004				
Effect on greenhouse gases	Reduction (t/a)				
	CFC-11				
	23				
Total net cost of action	Capital cost (1990$)	Operating cost (1990$/a)	Operating benefits (1990$/a)	Annual net cost (1990$/a)	
	$0	$0	$0	$0	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet					
Sources affected	Landfill methane emissions			Action code	land1
Action	MSW incineration				
Type of action	Prevent CH_4 emissions by converting to CO_2 during combustion				
Description	Incinerate MSW.				
Comments	Cost based on 364 tonnes per day unit. Benefits include landfill diversion credits				
References	OMOE 1991 [CH2M]				
Greenhouse gases	Methane and carbon dioxide				
Indirect impacts	Fly-ash and bottom ash (20 to 30 per cent by weight) may be hazardous.				
Quantity of source	12	units, each using		100 000	t MSW /a
Greenhouse gas quantity	794 167	per unit (kg/a)		9 530	Total (t/a)
Capital cost of action	$53 206 000	(1990$)/unit			
Operating cost of action	$6 750 000	(1990$)/unit/a			
Operating benefits	$4 040 008	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	100%				
Implementation schedule	2004				
Effect on greenhouse gases	Reductions (t/a)				
	CH_4	CO_2			
	9 530	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$638 472 000	$81 000 000	$48 480 094	$77 698 311	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Subdivisions:

Sub-code	Units	Reduction
LAND1a	3	2 383
LAND1b	1	794
LAND1c	7	5 559
LAND1d	1	794
Total	12	9 530

Action summary information sheet				
Sources affected	Landfill methane emissions		Action code	land3
Action	MSW incineration			
Type of action	Prevent CH4 emissions by converting to CO2 during combustion			
Description	Incinerate MSW.			
Comments	Cost based on 3000 tonnes per day unit. Benefits include landfill diversion credits			
References	OMOE 1991 [CH2M]			
Greenhouse gases	Methane and carbon dioxide			
Indirect impacts	Fly-ash and bottom ash (20 to 30 per cent by weight) may be hazardous.			
Quantity of source	8	units, each using	500 000	t MSW /a
Greenhouse gas quantity	4 189 000	per unit (kg/a)	29 323	Total (t/a)
Capital cost of action	$299 250 000	(1990$)/unit		
Operating cost of action	$21 750 000	(1990$)/unit/a		
Operating benefits	$20 200 039	(1990$)/unit/a		
Lifetime of action	20			
Delay in reduction	1			
Level of effectiveness	100%			
Implementation schedule	2004			
Effect on greenhouse gases	Reductions (t/a)			
	CH4	CO2		
	29 323	0		
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost
	$2 094 750 000	$152 250 000	$141 400 274	$156 199 325
Discount rate	Municipal	Social		
	3.00%	3.00%		

Action summary information sheet				
Sources affected	Landfill methane emissions		Action code	land4
Action	Household yard and food waste composting			
Type of action	Divert DOCs to household composters			
Description	Individual household scale composting of yard and food waste			
Comments	3 328 716 eligible households			
References	VHB and ERL, 1992 [383, p. A-17]			
Greenhouse gases	Methane and carbon dioxide			
Indirect impacts	Provides soil enhancer, qualifies for landfill diversion credit			
Quantity of source	3 328 716	units	0.36	t/a DOC-MSW
Greenhouse gas quantity	12.35	per unit (kg/a)	41 093	Total (t/a)
Capital cost of action	\$72	(1990\$)/unit		
Operating cost of action	\$0	(1990\$)/unit/a		
Operating benefits	\$18	(1990\$)/unit/a		
Lifetime of action	10			
Delay in reduction	1			
Level of effectiveness	100%			
Implementation schedule	2004			
Effect on greenhouse gases	Reductions (t/a)			
	CH4	CO2		
	41 093	0		
Total cost of action (\$1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost
	\$239 667 552	\$0	\$60 444 157	(\$33 318 242)
Discount rate	Municipal	Social		
	3.00%	3.00%		

Action summary information sheet					
Sources affected	Landfill methane emissions			Action code	land5
Action	Municipal yard waste composting				
Type of action	Divert yard waste to municipal composting facilities				
Description	Grass, leaves and brush collection and composting				
Comments	Cost based on an average of 15 yard waste composting programs in America, actual costs may vary with alternative collection schemes and composting technologies				
References	Conklin and Lindeberg, 1992.; VHB and ERL, 1992 [383]; OMOE 1990				
Greenhouse gases	Methane and carbon dioxide				
Indirect impacts	Provides soil enhancer. Some processes may produce odours.				
Quantity of source	40	units		8 368	t/a yard waste
Greenhouse gas quantity	344 385	per unit (kg/a)		13 431	Total (t/a)
Capital cost of action	$220 423	(1990$)/unit			
Operating cost of action	$165 774	(1990$)/unit/a			
Operating benefits	$422 106	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	100%				
Implementation schedule	2004				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	13 431	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$8 596 506	$6 465 197	$16 462 150	($9 701 707)	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet

Sources affected	Landfill methane emissions			Action code	land6
Action	Municipal DOC composting				
Type of action	Divert food and yard waste to municipal composters				
Description	Wet/dry material recovery facility with organic waste composting				
Comments	Cost based on two-stream wet/dry system including organic waste processing and composting proposed in Guelph				
References	VHB and ERL, 1992 [383]; OMOE 1990				
Greenhouse gases	Methane and carbon dioxide				
Indirect impacts	Provides soil enhancer. Some processes may produce odours.				
Quantity of source			20 units	44 000 t/a OW-MSW	
Greenhouse gas quantity	1 736 600	per unit (kg/a)		34 732	Total (t/a)
Capital cost of action	$13 999 762	(1990$)/unit			
Operating cost of action	$1 559 716	(1990$)/unit/a			
Operating benefits	$2 219 360	(1990$)/unit/a			
Lifetime of action	25				
Delay in reduction	1				
Level of effectiveness	100%				
Implementation schedule	2004				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	34 732	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$279 995 237	$31 194 323	$44 387 200	$2 973 253	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet					
Sources affected	Landfill methane emissions			Action code	land13
Action	MSW incineration				
Type of action	Prevent CH4 emissions by converting to CO2 during combustion				
Description	Incinerate MSW.				
Comments	Cost based on 364 tonnes per day unit. Benefits include landfill diversion credits				
References	OMOE 1991 [CH2M]				
Greenhouse gases	Methane and carbon dioxide				
Indirect impacts	Fly-ash and bottom ash (20 to 30 per cent by weight) may be hazardous.				
Quantity of source	12	units, each using		100 000	t MSW /a
Greenhouse gas quantity	3 129 500	per unit (kg/a)		37 554	Total (t/a)
Capital cost of action	$53 206 000	(1990$)/unit			
Operating cost of action	$6 750 000	(1990$)/unit/a			
Operating benefits	$4 040 008	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	10				
Level of effectiveness	100%				
Implementation schedule	1995				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	37 554	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$638 472 000	$81 000 000	$48 480 094	$101 378 673	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet					
Sources affected	Landfill methane emissions			Action code	land14
Action	MSW incineration				
Type of action	Prevent CH4 emissions by converting to CO2 during combustion				
Description	Incinerate MSW.				
Comments	Cost based on 660 tonnes per day unit. Benefits include landfill diversion credits				
References	OMOE 1991 [CH2M]				
Greenhouse gases	Methane and carbon dioxide				
Indirect impacts	Fly-ash and bottom ash (20 to 30 per cent by weight) may be hazardous.				
Quantity of source	0	units, each using		250 000	t MSW /a
Greenhouse gas quantity	0	per unit (kg/a)		0	Total (t/a)
Capital cost of action	$93 190 000	(1990$)/unit			
Operating cost of action	$15 875 000	(1990$)/unit/a			
Operating benefits	$10 100 020	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	10				
Level of effectiveness	100%				
Implementation schedule	1995				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	0	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$0	$0	$0	$0	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet					
Sources affected	Landfill methane emissions			Action code	land15
Action	MSW incineration				
Type of action	Prevent CH4 emissions by converting to CO2 during combustion				
Description	Incinerate MSW.				
Comments	Cost based on 3000 tonnes per day unit. Benefits include landfill diversion credits				
References	OMOE 1991 [CH2M]				
Greenhouse gases	Methane and carbon dioxide				
Indirect impacts	Fly-ash and bottom ash (20 to 30 per cent by weight) may be hazardous.				
Quantity of source	8	units, each using		500 000	t MSW /a
Greenhouse gas quantity	16 507 143	per unit (kg/a)		132 057	Total (t/a)
Capital cost of action	$299 250 000	(1990$)/unit			
Operating cost of action	$21 750 000	(1990$)/unit/a			
Operating benefits	$20 200 039	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	10				
Level of effectiveness	100%				
Implementation schedule	1995				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	132 057	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$2 394 000 000	$174 000 000	$161 600 312	$232 919 650	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet					
Sources affected	Landfill methane emissions			Action code	land16
Action	Household yard and food waste composting				
Type of action	Divert DOCs to household composters				
Description	Individual household scale composting of yard and food waste				
Comments	3 328 716 eligible households				
References	VHB and ERL, 1992 [383, p. A-17]				
Greenhouse gases	Methane and carbon dioxide				
Indirect impacts	Provides soil enhancer, qualifies for landfill diversion credit				
Quantity of source	3 328 716	units		0.36 t/a	DOC-MSW
Greenhouse gas quantity	48.65	per unit (kg/a)		161 928	Total (t/a)
Capital cost of action	$72	(1990$)/unit			
Operating cost of action	$0	(1990$)/unit/a			
Operating benefits	$18	(1990$)/unit/a			
Lifetime of action	10				
Delay in reduction	10				
Level of effectiveness	100%				
Implementation schedule	1995				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	161 928	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$239 667 552	$0	$60 444 157	($43 472 749)	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet					
Sources affected	Landfill methane emissions			Action code	Landf7
Action	Municipal yard waste composting				
Type of action	Divert yard waste to municipal composting facilities				
Description	Grass, leaves and brush collection and composting				
Comments	Cost based on an average of 15 yard waste composting programs in America, actual costs may vary with alternative collection schemes and composting technologies				
References	Conklin and Lindeberg, 1992.; VHB and ERL, 1992 [383]; OMOE 1990				
Greenhouse gases	Methane and carbon dioxide				
Indirect impacts	Provides soil enhancer. Some processes may produce odours.				
Quantity of source	40	units		8 368	t/a yard waste
Greenhouse gas quantity	1 357 051	per unit (kg/a)		52 925	Total (t/a)
Capital cost of action	$220 423	(1990$)/unit			
Operating cost of action	$165 774	(1990$)/unit/a			
Operating benefits	$422 106	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	10				
Level of effectiveness	100%				
Implementation schedule	1995				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	52 925	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$8 596 506	$6 465 197	$16 462 150	($12 658 527)	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet

Sources affected	Landfill methane emissions			Action code	Land18
Action	Municipal DOC composting				
Type of action	Divert food and yard waste to municipal composters				
Description	Wet/dry material recovery facility with organic waste composting				
Comments	Cost based on two-stream wet/dry system including organic waste processing and composting proposed in Guelph				
References	VHB and ERL, 1992 [383]; OMOE 1990				
Greenhouse gases	Methane and carbon dioxide				
Indirect impacts	Provides soil enhancer. Some processes may produce odours.				
Quantity of source	20	units		44 000	t/a OW-MSW
Greenhouse gas quantity	6 843 100	per unit (kg/a)		136 862	Total (t/a)
Capital cost of action	$13 999 762	(1990$)/unit			
Operating cost of action	$1 559 716	(1990$)/unit/a			
Operating benefits	$2 219 360	(1990$)/unit/a			
Lifetime of action	25				
Delay in reduction	10				
Level of effectiveness	100%				
Implementation schedule	1995				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	136 862	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$279 995 237	$31 194 323	$44 387 200	$3 879 421	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet					
Sources affected	Landfill methane emissions			Action code LFG2	
Action	Collect and flare landfill gas				
Type of action	Collect landfill gas				
Description	Install gas collection system and gas burner flare system				
Comments	Cost based on new landfill cost with conservative assumptions .				
References	VHB, 1991 [381].				
Greenhouse gases	Methane and carbon dioxide				
Indirect impacts					
Quantity of source	4	units, each receiving		2 500	t MSW /a
Greenhouse gas quantity	96 794	per unit (kg/a)		387	Total (t/a)
Capital cost of action	$246 855.97	(1990$)/unit			
Operating cost of action	$11 900.00	(1990$)/unit/a			
Operating benefits	$0	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	50%	of	8	units	
Implementation schedule	2004				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	387	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$987 424	$47 600	$0	$117 390	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet					
Sources affected	Landfill methane emissions			Action code LFG3	
Action	Collect and flare landfill gas				
Type of action	Collect landfill gas				
Description	Install gas collection system and gas burner flare system				
Comments	Cost based on new landfill cost with conservative assumptions .				
References	VHB, 1991 [381].				
Greenhouse gases	Methane and carbon dioxide				
Indirect impacts					
Quantity of source	8	units, each receiving		5 000	t MSW /a
Greenhouse gas quantity	193 588	per unit (kg/a)		1 549	Total (t/a)
Capital cost of action	$290 254.18	(1990$)/unit			
Operating cost of action	$11 900.00	(1990$)/unit/a			
Operating benefits	$0	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	50%	of	16	units	
Implementation schedule	2004				
Effect on greenhouse gases	Reduction (t/a)				
	CH4	CO2			
	1 549	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$2 322 033	$95 200	$0	$258 815	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet					
Sources affected	Landfill methane emissions			Action code LFG4	
Action	Collect and flare landfill gas				
Type of action	Collect landfill gas				
Description	Install gas collection system and gas burner flare system				
Comments	Cost based on new landfill cost with conservative assumptions .				
References	VHB, 1991 [381].				
Greenhouse gases	Methane and carbon dioxide				
Indirect impacts					
Quantity of source	7	units, each receiving		10 000	t MSW /a
Greenhouse gas quantity	387 175	per unit (kg/a)		2 710	Total (t/a)
Capital cost of action	$376 443.55	(1990$)/unit			
Operating cost of action	$11 900.00	(1990$)/unit/a			
Operating benefits	$0	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	50%	of	14	units	
Implementation schedule	2004				
Effect on greenhouse gases	Reduction (t/a)				
	CH4	CO2			
	2 710	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$2 635 105	$83 300	$0	$268 233	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet					
Sources affected	Landfill methane emissions			Action code LFG5	
Action	Collect and flare landfill gas				
Type of action	Collect landfill gas				
Description	Install gas collection system and gas burner flare system				
Comments	Cost based on new landfill cost with conservative assumptions .				
References	VHB, 1991 [381].				
Greenhouse gases	methane and carbon dioxide				
Indirect impacts					
Quantity of source	11	units, each receiving		25 000	t MSW /a
Greenhouse gas quantity	921 805	per unit (kg/a)		10 140	Total (t/a)
Capital cost of action	$590 460	(1990$)/unit			
Operating cost of action	$11 900.00	(1990$)/unit/a			
Operating benefits	$0	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	50%	of	22	units	
Implementation schedule	2004				
Effect on greenhouse gases	Reduction (t/a)				
	CH4	CO2			
	10 140	0			
Total cost of action ($1990)	l cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$6 495 059	$130 900	$0	$584 494	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet					
Sources affected	Landfill methane emissions			Action code LFG6	
Action	Collect and flare landfill gas				
Type of action	Collect landfill gas				
Description	Install gas collection system and gas burner flare system				
Comments	Cost based on new landfill cost with conservative assumptions .				
References	VHB, 1991 [381].				
Greenhouse gases	methane and carbon dioxide				
Indirect impacts					
Quantity of source	2	units, each using		50 000	t MSW /a
Greenhouse gas quantity	1 935 790	per unit (kg/a)		3 872	Total (t/a)
Capital cost of action	$907 040	(1990$)/unit			
Operating cost of action	$11 900	(1990$)/unit/a			
Operating benefits	$0	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	20%	of	10	units	
Implementation schedule	2004				
Effect on greenhouse gases	Reduction (t/a)				
	CH4	CO2			
	3 872	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$1 814 079	$23 800	$0	$150 107	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet					
Sources affected	Landfill methane emissions			Action code LFG7	
Action	Collect and flare landfill gas				
Type of action	Collect landfill gas				
Description	Install gas collection system and gas burner flare system				
Comments	Cost based on new landfill cost with conservative assumptions .				
References	VHB, 1991 [381].				
Greenhouse gases	methane and carbon dioxide				
Indirect impacts					
Quantity of source	1	units, each using		100 000	t MSW /a
Greenhouse gas quantity	3 871 538	per unit (kg/a)		2 323	Total (t/a)
Capital cost of action	$1 426 306	(1990$)/unit			
Operating cost of action	$13 040	(1990$)/unit/a			
Operating benefits	$0	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	15%	of	4	units	
Implementation schedule	2004				
Effect on greenhouse gases	Reduction (t/a)				
	CH4	CO2			
	2 323	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$855 784	$7 824	$0	$67 306	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet

Sources affected	Landfill methane emissions			Action code LFG8	
Action	Collect and flare landfill gas				
Type of action	Collect landfill gas				
Description	Install gas collection system and gas burner flare system				
Comments	Cost based on new landfill cost with conservative assumptions .				
References	VHB, 1991 [381].				
Greenhouse gases	methane and carbon dioxide				
Indirect impacts					
Quantity of source	1	units, each using		150 000	t MSW /a
Greenhouse gas quantity	5 807 342	per unit (kg/a)		3 484	Total (t/a)
Capital cost of action	$2 183 482	(1990$)/unit			
Operating cost of action	$14 180	(1990$)/unit/a			
Operating benefits	$0	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	10%	of	6	units	
Implementation schedule	2004				
Effect on greenhouse gases	Reduction (t/a)				
	CH4	CO2			
	3 484	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$1 310 089	$8 508	$0	$99 464	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet

Sources affected	Landfill methane emissions			Action code LFG10	
Action	Collect and flare landfill gas				
Type of action	Collect landfill gas				
Description	Install gas collection system and gas burner flare system				
Comments	Cost based on new landfill cost with conservative assumptions .				
References	VHB, 1991 [381].				
Greenhouse gases	methane and carbon dioxide				
Indirect impacts					
Quantity of source	1	units, each using		500 000	t MSW /a
Greenhouse gas quantity	19 357 688	per unit (kg/a)		15 486	Total (t/a)
Capital cost of action	$5 470 780	(1990$)/unit			
Operating cost of action	$21 400	(1990$)/unit/a			
Operating benefits	$0	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	10%	of	8	units	
Implementation schedule	2004				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	15 486	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$4 376 624	$17 120	$0	$320 637	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet

Sources affected	Landfill methane emissions			Action code LFG11	
Action	Recover landfill gas for energy				
Type of action	Collect landfill gas				
Description	Install gas collection system and gas-fired thermal generator				
Comments	Cost based on new landfill cost with conservative assumptions . Benefits include sale of generated electricity.				
References	VHB, 1991 [381].				
Greenhouse gases	Methane and carbon dioxide				
Indirect impacts	Offsets thermal generation for secondary ghg reductions				
Quantity of source	4	units, each using		2 500	t MSW /a
Greenhouse gas quantity	96 794	per unit (kg/a)		387	Total (t/a)
Capital cost of action	$365 310	(1990$)/unit			
Operating cost of action	$21 771	(1990$)/unit/a			
Operating benefits	$36 433	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	50%	of	8	units	
Implementation schedule	2004				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	387	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$1 461 241	$87 085	$145 733	$40 757	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet

Sources affected	Landfill methane emissions			Action code LFG12	
Action	Recover landfill gas for energy .				
Type of action	Collect landfill gas				
Description	Install gas collection system and gas-fired thermal generator				
Comments	Cost based on new landfill cost with conservative assumptions . Benefits include sale of generated electricity.				
References	VHB, 1991 [381].				
Greenhouse gases	methane and carbon dioxide				
Indirect impacts	Offsets thermal generation for secondary ghg reductions				
Quantity of source	8	units, each using		5 000	t MSW /a
Greenhouse gas quantity	258 117	per unit (kg/a)		2 065	Total (t/a)
Capital cost of action	$527 163	(1990$)/unit			
Operating cost of action	$31 642	(1990$)/unit/a			
Operating benefits	$72 867	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	50%	of	16	units	
Implementation schedule	2004				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	2 065	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$4 217 300	$253 139	$582 934	($47 716)	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet					
Sources affected	Landfill methane emissions			Action code LFG13	
Action	Recover landfill gas for energy				
Type of action	Collect landfill gas				
Description	Install gas collection system and gas-fired thermal generator				
Comments	Cost based on new landfill cost with conservative assumptions . Benefits include sale of generated electricity.				
References	VHB, 1991 [381].				
Greenhouse gases	methane and carbon dioxide				
Indirect impacts	Offsets thermal generation for secondary ghg reductions				
Quantity of source	7	units, each using		10 000	t MSW /a
Greenhouse gas quantity	387 175	per unit (kg/a)		2 710	Total (t/a)
Capital cost of action	$850 260	(1990$)/unit			
Operating cost of action	$51 385	(1990$)/unit/a			
Operating benefits	$145 733	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	50%	of	14	units	
Implementation schedule	2004				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	2 710	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$5 951 822	$359 693	$1 020 134	($268 196)	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet					
Sources affected	Landfill methane emissions			Action code LFG14	
Action	Recover landfill gas for energy				
Type of action	Collect landfill gas				
Description	Install gas collection system and gas-fired thermal generator				
Comments	Cost based on new landfill cost with conservative assumptions . Benefits include sale of generated electricity.				
References	VHB, 1991 [381].				
Greenhouse gases	methane and carbon dioxide				
Indirect impacts	Offsets thermal generation for secondary ghg reductions				
Quantity of source	11	units, each using		25 000	t MSW /a
Greenhouse gas quantity	921 805	per unit (kg/a)		10 140	Total (t/a)
Capital cost of action	$1 775 002	(1990$)/unit			
Operating cost of action	$110 612	(1990$)/unit/a			
Operating benefits	$364 333	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	50%	of	22	units	
Implementation schedule	2004				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	10 140	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$19 525 020	$1 216 730	$4 007 668	($1 522 907)	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet					
Sources affected	Landfill methane emissions			Action code LFG15	
Action	Recover landfill gas for energy				
Type of action	Collect landfill gas				
Description	Install gas collection system and gas-fired thermal generator				
Comments	Cost based on new landfill cost with conservative assumptions . Benefits include sale of generated electricity.				
References	VHB, 1991 [381].				
Greenhouse gases	methane and carbon dioxide				
Indirect impacts	Offsets thermal generation for secondary ghg reductions				
Quantity of source	8	units, each using		50 000	t MSW /a
Greenhouse gas quantity	1 935 790	per unit (kg/a)		15 486	Total (t/a)
Capital cost of action	$3 276 123	(1990$)/unit			
Operating cost of action	$209 324	(1990$)/unit/a			
Operating benefits	$728 667	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	80%	of	10	units	
Implementation schedule	2004				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	15 486	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$26 208 987	$1 674 589	$5 829 336	($2 464 884)	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet

Sources affected	Landfill methane emissions			Action code LFG16	
Action	Recover landfill gas for energy				
Type of action	Collect landfill gas				
Description	Install gas collection system and gas-fired thermal generator				
Comments	Cost based on new landfill cost with conservative assumptions . Benefits include sale of generated electricity.				
References	VHB, 1991 [381].				
Greenhouse gases	methane and carbon dioxide				
Indirect impacts	Offsets thermal generation for secondary ghg reductions				
Quantity of source	3	units, each using		100 000	t MSW /a
Greenhouse gas quantity	3 871 538	per unit (kg/a)		13 163	Total (t/a)
Capital cost of action	$6 164 474	(1990$)/unit			
Operating cost of action	$407 887	(1990$)/unit/a			
Operating benefits	$1 457 334	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	85%	of	4	units	
Implementation schedule	2004				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	13 163	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$20 959 211	$1 386 817	$4 954 936	($2 224 110)	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet

Sources affected	Landfill methane emissions			Action code LFG17	
Action	Recover landfill gas for energy				
Type of action	Collect landfill gas				
Description	Install gas collection system and gas-fired thermal generator				
Comments	Cost based on new landfill cost with conservative assumptions . Benefits include sale of generated electricity.				
References	VHB, 1991 [381].				
Greenhouse gases	methane and carbon dioxide				
Indirect impacts	Offsets thermal generation for secondary ghg reductions				
Quantity of source	5	units, each using		150 000	t MSW /a
Greenhouse gas quantity	5 807 342	per unit (kg/a)		31 360	Total (t/a)
Capital cost of action	$9 290 733	(1990$)/unit			
Operating cost of action	$606 451	(1990$)/unit/a			
Operating benefits	$2 186 001	(1990$)/unit/a			
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	90%	of	6	units	
Implementation schedule	2004				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	31 360	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$50 169 960	$3 274 835	$11 804 405	($5 312 082)	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet

Sources affected	Landfill methane emissions			Action code LFG19	
Action	Recover landfill gas for energy				
Type of action	Collect landfill gas				
Description	Install gas collection system and gas-fired thermal generator				
Comments	Cost based on new landfill cost with conservative assumptions . Benefits include sale of generated electricity.				
References	VHB, 1991 [381].				
Greenhouse gases	methane and carbon dioxide				
Indirect impacts	Offsets thermal generation for secondary ghg reductions				
Quantity of source	7	units, each using		500 000	t MSW /a
Greenhouse gas quantity	19 357 688	per unit (kg/a)		139 375	Total (t/a)
Capital cost of action	$29 161 618	(1990$)/unit		$117	per tonne
Operating cost of action	$1 995 636	(1990$)/unit/a		$8	per tonne
Operating benefits	$7 286 670	(1990$)/unit/a		$29	per tonne
Lifetime of action	20				
Delay in reduction	1				
Level of effectiveness	90%	of	8	units	
Implementation schedule	2004				
Effect on greenhouse gases	Reductions (t/a)				
	CH4	CO2			
	139 375	0			
Total cost of action ($1990)	Capital cost	Annual operating cost	Annual operating benefits	Annual net cost	
	$209 963 650	$14 368 583	$52 464 023	($24 702 063)	
Discount rate	Municipal	Social			
	3.00%	3.00%			

Action summary information sheet

Sources affected	Livestock methane emissions (1)	Action code live1

Action	Treat dairy cattle with rBST				
Type of action	Increase per animal milk yield and reduce herd size.				
Description	Recombinant bovine somatotropin, used with good producing cows increases milk production				
Comments	Assuming provincial quotas, producer prices, levies and subsidies remain unchanged, herd sizes are reduced, variable costs are reduced				
References	Deloitte and Touche, 1990, and Agriculture Canada, 1990.				
Greenhouse gases	Methane				
Indirect impacts	Reduces herd size, energy inputs and land use				
Quantity of source	28 168	animals, if	5.60%	reduction from	503 000
Greenhouse gas quantity	58.47	per animal (kg/a)		1647.11	Total (t/a)
Capital cost of action	$0.00	(1990$)/animal			
Operating cost of action	($1 016.69)	(1990$)/animal/a		applied to total herd	
Operating benefits	$0.00	(1990$)/unit/a			
Lifetime of action	1	years			
Delay in reduction	0	years			
Level of effectiveness	100%				
Implementation schedule	2005				
Effect on greenhouse gases	Reduction (t/a)				
	CH4	CO2			
	1 647	0	(t/a)		
Total cost of action	Capital cost (1990$)	Annual operating cost (1990$/a)	Annual operating benefits (1990$/a)	Annual net cost (1990$/a)	
	$0	($1 017)	$0	($1 017)	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet

Sources affected	Methane from livestock manure	Action code	Live2
Action	Anaerobically digest manure and collect biogas for energy		
Type of action	Biogas collection		
Description	Retrofitted manure handling, digester and generator		

Action summary information sheet						
Sources affected	Methane from livestock manure				Action code	Live2
Action	Anaerobically digest manure and collect biogas for energy					
Type of action	Biogas collection					
Comments						
References	Ralph G. Winfield, 1986, and NRC, 1982.					
Greenhouse gases	Methane and carbon dioxide					
Indirect impacts	Reduces odours and leachate from manure storage, biogas used for energy					
Quantity of source	1	units, each produces			471.17	m3 CH4 /d
Greenhouse gas quantity	123 273	per unit (kg/a)			123.27	Total (t/a)
Capital cost of action	$258 690.18	(1990$)/unit				
Operating cost of action	$15 328.43	(1990$)/unit/a				
Operating benefits	$10 572.83					
Lifetime of action	20	years				
Delay in reduction	0	years				
Level of effectiveness	100%					
Implementation schedule	2005					
Effect on greenhouse gases	Reduction (t/a)					
	CH4	CO2				
	123	(322)	(t/a)			
Total cost of action	Capital cost (1990$)	Annual operating cost (1990$/a)	Annual operating benefits (1990$/a)	Annual net cost (1990$/a)		
	$258 690	$15 328	$10 573	$27 309		
Discount rate	Private	Social				
	6.00%	3.00%				

Action summary information sheet			
Sources affected	Methane from livestock manure	Action code	Live3

Action	Anaerobically digest manure, collect biogas for energy, single-cell protein for dietary supplement			
Type of action	Biogas collection and protein recovery			
Description	Retrofitted manure handling, digester and generator, protein centrifuge			
Comments	Single-cell protein recovery for animal feed supplement is experimental			
References	Ralph G. Winfield, 1986, and NRC, 1982.			
Greenhouse gases	Methane and carbon dioxide			
Indirect impacts	Reduces odours and leachate from manure storage, biogas used for energy			
Quantity of source	1	units, each produces	471.17	m3 CH4 /d
Greenhouse gas quantity	123 273	per unit (kg/a)	123.27	Total (t/a)
Capital cost of action	$358 803.27	(1990$)/unit		
Operating cost of action	$15 328.43	(1990$)/unit/a		
Operating benefits	$45 372.83	(1990$)/unit/a		
Lifetime of action	20	years		
Delay in reduction	0	years		
Level of effectiveness	100%			
Implementation schedule	2005			
Effect on greenhouse gases	Reduction (t/a)			
	CH4	CO2		
	123	(322)	(t/a)	
Total cost of action	Capital cost (1990$)	Annual operating cost (1990$/a)	Annual operating benefits (1990$/a)	Annual net cost (1990$/a)
	$358 803	$15 328	$45 373	$1 238
Discount rate	Private	Social		
	6.00%	3.00%		

Action summary information sheet					
Sources affected	Livestock methane emissions			Action code Live4	
Action	Human diet change				
Type of action	Substitute pork for beef				
Description	Pigs emit less CH4 per kilo of product than do cows.				
Comments	Assuming provincial quotas, producer prices, levies and subsidies remain unchanged, herd sizes are reduced, variable costs are reduced				
References	OMAF, 1991. Ontario Pork Producers' Marketing Board, 1992.				
Greenhouse gases	Methane				
Indirect impacts	Requires				
Quantity of source	1 000 000	units, each comprising		1	kg meat
Greenhouse gas quantity	0.0768	per unit (kg/a)		76.80	Total (t/a)
Capital cost of action	$0.00	(1990$)/unit			
Operating cost of action	$0.65	(1990$)/unit/a			
Operating benefits	$0.00	(1990$)/unit/a			
Lifetime of action	1	years			
Delay in reduction	0	years			
Level of effectiveness	100%				
Implementation schedule	2005				
Effect on greenhouse gases	Reduction (t/a)				
	CH4				
	77	(t/a)			
Total cost of action	Capital cost (1990$)	Annual operating cost (1990$/a)	Annual operating benefits (1990$/a)	Annual net cost (1990$/a)	
	$0	$653 340	$0	$653 340	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet

Sources affected	Mobile air conditioners		Action code Mobile1		
Action	Chemical substitution				
Type of action	HFC-134a				
Description	Refrigerant for mobile air conditioners - new vehicles				
Comments	New vehicles. Currently available. GWP 0.34 relative to CFC-11. Minor modifications to cooling system required: lubricants and seals, otherwise a drop-in technology.				
References	Stevenson Kellogg Ernst & Young; ICF 1990; Hoffman 1990; UNEP 1989; Environment Canada 1989. Abt Associates 1989; UNEP 1991; Lashof and Tirpak 1990.				
Greenhouse gases	CFC-12; HCFC-22 (some new vehicles only)				
Indirect impacts	Eliminates ODP. 2% fuel use penalty.				
Quantity of source	4 988 993	units			
Greenhouse gas quantity	0.4	per unit (kg/a)		1 996	Total (t/a)
Capital cost of action	$115	(1990$)/vehicle			
Operating cost of action	$49	(1990$)/vehicle/a			
Operating benefits		n/a			
Lifetime of action	10	years			
Delay in reduction	10	years			
Level of effectiveness	100.0%				
Implementation schedule	1995				
Effect on greenhouse gases	Reduction (t/a)				
	CFC-12	HCFC-22	HFC-134a		
	1 996	na	-1 996		
Total net cost of action	Capital cost (1990$)	Operating cost (1990$/a)	Operating benefits (1990$/a)	Annual net cost (1990$/a)	* Changes in operating cost exclude costs associated with increased fuel consumption.
	$571 638 825	$246 947 972	$0	$581 336 691	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet

Sources affected	Mobile air conditioners		Action code Mobile2		
Action	Chemical substitution				
Type of action	HFC-134a				
Description	Refrigerant for mobile air conditioners - new vehicles				
Comments	New vehicles. Currently available. GWP 0.34 relative to CFC-11. Minor modifications to cooling system required: lubricants and seals, otherwise a drop-in technology.				
References	Stevenson Kellogg Ernst & Young; ICF 1990; Hoffman 1990; UNEP 1989; Environment Canada 1989. Abt Associates 1989; UNEP 1991; Lashof and Tirpak 1990.				
Greenhouse gases	CFC-12; HCFC-22 (some new vehicles only)				
Indirect impacts	Eliminates ODP. 2% fuel use penalty.				
Quantity of source	2 624 514	units			
Greenhouse gas quantity	0.4	per unit (kg/a)		1 050	Total (t/a)
Capital cost of action	$115	(1990$)/vehicle			
Operating cost of action	$49	(1990$)/vehicle/a			
Operating benefits		n/a			
Lifetime of action	10	years			
Delay in reduction	5	years			
Level of effectiveness	100.0%				
Implementation schedule	2000				
Effect on greenhouse gases	Reduction (t/a)				
	CFC-12	HCFC-22	HFC-134a		
	1 050	na	-1 050		
Total net cost of action	Capital cost (1990$)	Operating cost (1990$/a)	Operating benefits (1990$/a)	Annual net cost (1990$/a)	* Changes in operating cost exclude costs associated with increased fuel consumption.
	$300 716 766	$129 909 643	$0	$208 933 815	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet					
Sources affected	Mobile air conditioners			Action code	Mobile3
Action	Chemical substitution				
Type of action	HFC-134a				
Description	Refrigerant for mobile air conditioners - new vehicles				
Comments	New vehicles. Currently available. GWP 0.34 relative to CFC-11. Minor modifications to cooling system required: lubricants and seals, otherwise a drop-in technology.				
References	Stevenson Kellogg Ernst & Young; ICF 1990; Hoffman 1990; UNEP 1989; Environment Canada 1989. Abt Associates 1989; UNEP 1991; Lashof and Tirpak 1990.				
Greenhouse gases	CFC-12; HCFC-22 (some new vehicles only)				
Indirect impacts	Eliminates ODP. 2% fuel use penalty.				
Quantity of source	530 616	units			
Greenhouse gas quantity	0.4	per unit (kg/a)		212	Total (t/a)
Capital cost of action	$115	(1990$)/vehicle			
Operating cost of action	$49	(1990$)/vehicle/a			
Operating benefits		n/a			
Lifetime of action	10	years			
Delay in reduction	1	years			
Level of effectiveness	100.0%				
Implementation schedule	2004				
Effect on greenhouse gases	Reduction (t/a)				
	CFC-12	HCFC-22	HFC-134a		
	212	na	212		
Total net cost of action	Capital cost (1990$)	Operating cost (1990$/a)	Operating benefits (1990$/a)	Annual net cost (1990$/a)	* Changes in operating cost exclude costs associated with increased fuel consumption.
	$60 797 988	$26 264 731	$0	$36 596 743	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet

Sources affected	Mobile air conditioners			Action code	Mobile4
Action	Chemical substitution				
Type of action	HFC-134a				
Description	Refrigerant for mobile air conditioners - retrofitted vehicles/ recovery and disposal of CFC.				
Comments	GWP 0.34 relative to CFC-11. Minor modifications to cooling system required: lubricants and seals, otherwise a drop-in technology.				
References	Stevenson Kellogg Ernst & Young; ICF 1990; Hoffman 1990; UNEP 1989; Environment Canada 1989. Abt Associates 1989; UNEP 1991; Lashof and Tirpak 1990.				
Greenhouse gases	CFC-12; HCFC-22 (some new vehicles only)				
Indirect impacts	Eliminates ODP. 2% fuel use penalty.				
Quantity of source	3 870 310	units			
Greenhouse gas quantity	0.4	per unit (kg/a)		1 548	Total (t/a)
Capital cost of action	$436	(1990$)/vehicle		Retrofit and repair cost,	
Operating cost of action	$49	(1990$)/vehicle/a		including incineration.	
Operating benefits		n/a			
Lifetime of action	10	years			
Delay in reduction	1	years			
Level of effectiveness	100.0%				
Implementation schedule	2004				
Effect on greenhouse gases	Reduction (tonnes)				
	CFC-12	HCFC-22	HFC-134a		
	1 548	na	1 548		
Total net cost of action	Capital cost (1990$)	Operating cost (1990$/a)	Operating benefits (1990$/a)	Annual net cost (1990$/a)	* Changes in operating cost exclude costs associated with increased fuel consumption.
	$1 687 430 441	$194 516 213	$0	$449 210 978	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet

Sources affected	Mobile Air Conditioners			Action code Mobile5	
Action	Reduction				
Type of action	Recovery and incineration				
Description	Capture of CFCs from mobile air conditioners prior to wrecking and incineration				
Comments	Emissions arise from mobile air conditioners during wrecking of retired vehicle stock. Emissions equal to full charge of cooling system. Wreckers would recover CFCs for re-use or disposal.				
References	ICF 1990; Hoffman 1990; UNEP 1989; Stevenson Kellogg Ernst & Young 1989; Environment Canada 1989.				
Greenhouse gases	CFC-12; HCFC-22 (new vehicles only)				
Indirect impacts	Reduces ODP.				
Quantity of source	14	wreckers	410 248	vehicles	
Greenhouse gas quantity	0.89	per unit (kg/a)		365	Total (t/a)
Capital cost of action	$5 000	(1990$)/per wrecker		Including incineration.	
Operating cost of action	$49	(1990$)/unit/a			
Operating benefits		n/a			
Lifetime of action	10	years			
Delay in reduction	1	years			
Level of effectiveness	95.0%				
Implementation schedule	2004				
Effect on greenhouse gases	Reduction (t/a)				
	CFC-12	HCFC-22			
	347				
Total net cost of action	Capital cost (1990$)	Operating cost (1990$/a)	Operating benefits (1990$/a)	Annual net cost (1990$/a)	* Changes in operating cost exclude costs associated with increased fuel consumption.
	$70 000	$20 618 465	$0	$21 897 454	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet					
Sources affected	Mobile Air Conditioners		Action code Mobile6		
Action	Reduction				
Type of action	Recovery and incineration/eliminate mobile air conditioners				
Description	Capture of CFCs from mobile air conditioners at the servicing level.				
Comments	Emissions arise from mobile air conditioners annually, about 0.4 kg/vehicle/a.				
References	ICF 1990; Hoffman 1990; UNEP 1989; Stevenson Kellogg Ernst & Young 1989; Environment Canada 1989.				
Greenhouse gases	CFC-12; HCFC-22 (some new vehicles only)				
Indirect impacts	Reduces ODP and vehicle energy use.				
Quantity of source	486	Air conditioning servicing stations and garages	3 870 310	vehicles	
Greenhouse gas quantity	0.4	per unit (kg/a)		1 548	Total (t/a)
Capital cost of action	$5 000	(1990$)/service station		Including incineration.	
Operating cost of action	$49	(1990$)/vehicle/a			
Operating benefits		n/a			
Lifetime of action	10	years			
Delay in reduction	1	years			
Level of effectiveness	95.0%				
Implementation schedule	2004				
Effect on greenhouse gases	Reduction (t/a)				
	CFC-12				
	1 471				
Total net cost of action	Capital cost (1990$)	Operating cost (1990$/a)	Operating benefits (1990$/a)	Annual net cost (1990$/a)	* Changes in operating cost exclude costs associated with increased fuel consumption.
	$2 430 000	$206 537 154	$0	$206 537 154	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet

Sources affected	methane emissions from the natural gas industry			Action code NG1	
Action	blowdown gas recovery				
Type of action	recover gas vented during pipeline blowdown				
Description	gas recovery facility at compressor stations				
Comments	Based on data from BR for 5 compressor units at the Dawn Operations Centre.				
References	Union Gas, 1992.				
Greenhouse gases	methane				
Indirect impacts	Recovers natural gas, energy savings				
Quantity of source	1	unit(s) each recovering		15000	m3/a
Greenhouse gas quantity	10 752	per unit (kg/a)		11	Total (t/a)
Capital cost of action	$1 000 000	(1990$)/unit			
Operating cost of action	$0	(1990$)/unit/a			
Operating benefit of action	$1 550	(1990$)/unit/a		$0.1033	per m3
Lifetime of action	30	years			
Delay in reduction	0	years			
Level of effectiveness	100%				
Implementation schedule	1991				
Effect on greenhouse gases	Reduction (t/a)				
	CH4	CO2			
	11	(28)	(t/a)		
Total cost of action	Capital cost (1990$)	Annual operating cost (1990$/a)	Annual operating benefits (1990$/a)	Annual net cost (1990$/a)	
	$1 000 000	$0	$1 550	$164 252	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet

Sources affected	Rigid foams		Action code Rigid1		
Action	Reduction				
Type of action	Reduce amount of CFC-11 used in manufacturing polyurethane foams.				
Description	Reduce CFC-11 as an auxiliary blowing agent from 13 to 6.5 per cent.				
Comments	Already in use. Short term solution. Applicable for all rigid foam production.				
References	Stevenson Kellogg Ernst & Whinney 1989; Lashof and Tirpak 1990; Environment Canada 1989; UNEP 1991.				
Greenhouse gases	CFC-11				
Indirect impacts	None.				
Quantity of source	7 185	tonnes			
Greenhouse gas quantity	na	per unit (kg/a)		323	Total (t/a)
Capital cost of action	$0	(1990$)/unit			
Operating cost of action	$0	(1990$)/unit/a			
Operating benefits	n/a				
Lifetime of action	20	year			
Delay in reduction	1	year			
Level of effectiveness	50.0%				
Implementation schedule	2004				
Effect on greenhouse gases	Reduction (t/a)				
	CFC-11				
	162				
Total net cost of action	Capital cost (1990$)	Operating cost (1990$/a)	Operating benefits (1990$/a)	Annual net cost (1990$/a)	
	$0	$0	$0	$0	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet

Sources affected	Rigid foams		Action code Rigid2		
Action	Reduction				
Type of action	Reduce amount of CFC-11 used in manufacturing polyurethane foams.				
Description	Reduce CFC-11 as an auxiliary blowing agent from 13 to 6.5 per cent.				
Comments	Already in use. Short term solution. Applicable for all rigid foam production.				
References	Stevenson Kellogg Ernst & Whinney 1989; Lashof and Tirpak 1990; Environment Canada 1989; UNEP 1991.				
Greenhouse gases	CFC-11				
Indirect impacts	None.				
Quantity of source	7 185	tonnes			
Greenhouse gas quantity	na	per unit (kg/a)		1 617	Total (t/a)
Capital cost of action	$0	(1990$)/unit			
Operating cost of action	$0	(1990$)/unit/a			
Operating benefits	n/a				
Lifetime of action	20	year			
Delay in reduction	5	year			
Level of effectiveness	50.0%				
Implementation schedule	2000				
Effect on greenhouse gases	Reduction (t/a)				
	CFC-11				
	808				
Total net cost of action	Capital cost (1990$)	Operating cost (1990$/a)	Operating benefits (1990$/a)	Annual net cost (1990$/a)	
	$0	$0	$0	$0	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet					
Sources affected	Rigid foams		Action code Rigid3		
Action	Reduction				
Type of action	Reduce amount of CFC-11 used in manufacturing polyurethane foams.				
Description	Reduce CFC-11 as an auxiliary blowing agent from 13 to 6.5 per cent.				
Comments	Already in use. Short term solution. Applicable for all rigid foam production.				
References	Stevenson Kellogg Ernst & Whinney 1989; Lashof and Tirpak 1990; Environment Canada 1989; UNEP 1991.				
Greenhouse gases	CFC-11				
Indirect impacts	None.				
Quantity of source	7 185	tonnes			
Greenhouse gas quantity	na	per unit (kg/a)		3 233	Total (t/a)
Capital cost of action	$0	(1990$)/unit			
Operating cost of action	$0	(1990$)/unit/a			
Operating benefits	n/a				
Lifetime of action	20	year			
Delay in reduction	10	year			
Level of effectiveness	50.0%				
Implementation schedule	1995				
Effect on greenhouse gases	Reduction (t/a)				
	CFC-11				
	1 617				
Total net cost of action	Capital cost (1990$)	Operating cost (1990$/a)	Operating benefits (1990$/a)	Annual net cost (1990$/a)	
	$0	$0	$0	$0	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet

Sources affected	Rigid foams		Action code Rigid4		
Action	Chemical substitution				
Type of action	HCFC-123				
Description	Rigid polyurethane insulating foams. Drop-in alternative. No capital investment expected. Operating costs will increase 10 to 20 per cent resulting from increased cost of HCFC-123. As HCFC-123 becomes more readily available in the future,				
Comments	increases in operating costs are expected to be minimal. Most rigid polyurethane foam is imported into Canada. Some R&D costs expected.Commercial use depends on outcome of toxicity tests.				
References	Abt Associates 1989; Bach and Jain 1990; Environment Canada 1989; Stevenson Kellogg Ernst & Young 1989; Jeffs, Rosebotham and Thomas 1990; Jeffs and Sparrow 1990; Cunningham, Rosebotham and Sparrow 1990; Lashof and Tirpak 1990; UNEP 1991.				
Greenhouse gases	CFC-11 and CFC-12				
Indirect impacts	Reduces ODP.				
Quantity of source	7 185	tonnes of foam insulation			
Greenhouse gas quantity	45	per unit (kg/a)		323	Total (t/a)
Capital cost of action	$110 000	(1990$)/unit			
Operating cost of action	$0.00	(1990$)/unit/a			
Operating benefits	n/a				
Lifetime of action	20	years			
Delay in reduction	1	years			
Level of effectiveness	100.0%				
Implementation schedule	2004				
Effect on greenhouse gases	Reduction (t/a)				
	CFC-11	HCFC-123			
	323	323			
Total net cost of action	Capital cost (1990$)	Operating cost (1990$/a)	Operating benefits (1990$/a)	Annual net cost (1990$/a)	
	$110 000	$0	$0	$10 166	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet

Sources affected	Rigid foams		Action code Rigid5		
Action	Chemical substitution				
Type of action	HCFC-123				
Description	Rigid polyurethane insulating foams. Drop-in alternative. No capital investment expected. Operating costs will increase 10 to 20 per cent resulting from increased cost of HCFC-123. As HCFC-123 becomes more readily available in the future,				
Comments	increases in operating costs are expected to be minimal. Most rigid polyurethane foam is imported into Canada. Some R&D costs expected.Commercial use depends on outcome of toxicity tests.				
References	Abt Associates 1989; Bach and Jain 1990; Environment Canada 1989; Stevenson Kellogg Ernst & Young 1989; Jeffs, Rosebotham and Thomas 1990; Jeffs and Sparrow 1990; Cunningham, Rosebotham and Sparrow 1990; Lashof and Tirpak 1990; UNEP 1991.				
Greenhouse gases	CFC-11 and CFC-12				
Indirect impacts	Reduces ODP.				
Quantity of source	7 185	tonnes of foam insulation			
Greenhouse gas quantity	225	per unit (kg/a)		1 617	Total (t/a)
Capital cost of action	$110 000	(1990$)/unit			
Operating cost of action	$0.00	(1990$)/unit/a			
Operating benefits	n/a				
Lifetime of action	20	years			
Delay in reduction	5	years			
Level of effectiveness	100.0%				
Implementation schedule	2000				
Effect on greenhouse gases	Reduction (t/a)				
	CFC-11	HCFC-123			
	1 617	1 617			
Total net cost of action	Capital cost (1990$)	Operating cost (1990$/a)	Operating benefits (1990$/a)	Annual net cost (1990$/a)	
	$110 000	$0	$0	$12 834	
Discount rate	Private	Social			
	6.00%	3.00%			

Action summary information sheet

Sources affected	Rigid foams		Action code Rigid6		
Action	Chemical substitution				
Type of action	HCFC-123				
Description	Rigid polyurethane insulating foams. Drop-in alternative. No capital investment expected. Operating costs will increase 10 to 20 per cent resulting from increased cost of HCFC-123. As HCFC-123 becomes more readily available in the future,				
Comments	increases in operating costs are expected to be minimal. Most rigid polyurethane foam is imported into Canada. Some R&D costs expected.Commercial use depends on outcome of toxicity tests.				
References	Abt Associates 1989; Bach and Jain 1990; Environment Canada 1989; Stevenson Kellogg Ernst & Young 1989; Jeffs, Rosebotham and Thomas 1990; Jeffs and Sparrow 1990; Cunningham, Rosebotham and Sparrow 1990; Lashof and Tirpak 1990; UNEP 1991.				
Greenhouse gases	CFC-11 and CFC-12				
Indirect impacts	Reduces ODP.				
Quantity of source	7 185	tonnes of foam insulation			
Greenhouse gas quantity	675	per unit (kg/a)		4 850	Total (t/a)
Capital cost of action	$110 000	(1990$)/unit			
Operating cost of action	$0.00	(1990$)/unit/a			
Operating benefits	n/a				
Lifetime of action	20	years			
Delay in reduction	15	years			
Level of effectiveness	100.0%				
Implementation schedule	1995				
Effect on greenhouse gases	Reduction (t/a)				
	CFC-11	HCFC-123			
	4 850	4 850			
Total net cost of action	Capitsl cost (1990$)	Operating cost (1990$/a)	Operating benefits (1990$/a)	Annual net cost (1990$/a)	
	$110 000	$0	$0	$22 984	
Discount rate	Private	Social			
	6.00%	3.00%			

Appendix B Modelling framework

A general model for determining and plotting emission reduction costs has been developed which offers the following features:

- ability to show effects on specific contaminants or groups of contaminants adjusted for their global warming potential (GWP)
- ability to test implications of alternative GWPs
- ability to show effects on either private or social costs
- ability to specify different discount rates for different sectors and for social or private cost analyses
- adjustments for delays in achieving emissions reductions.

Basic input data for the model are from the action summary sheets in Appendix A. Data from the sheets incorporated into the model include: capital and operating costs, estimates of reductions (or increases) by contaminant species, lifetime over which the actions and measures are applicable, and the time period between investment and realization of emissions reductions.

The model proceeds through three main sequences:

- estimation of carbon dioxide equivalences
- determination of private or social costs
- determination of incremental unit costs
- construction of the abatement cost curve.

Each of these steps is described below, and sample calculations are presented.

B.1 Estimation of carbon dioxide equivalence

The format for estimating carbon dioxide equivalences is presented in Table B-1. Some measures will result in increases in emissions of some greenhouse gases. For example, substituting HFCs for CFCs will reduce some greenhouse gas emissions (e.g. CFC-12) but will increase others (e.g. HFC-134a). The effect of different GWPs can be readily assessed, and the effects of actions or measures on individual compounds can be assessed by setting GWPs to zero for all compounds except those of interest.

Table B-1 Framework for estimating carbon dioxide equivalences

		CO_2	CH_4	N_2O	CFC-11	CFC-12	HCFC-13	HCFC-22	
Global warming potential (relative to CO_2)		1	21	290	3500	7300	1200	1500	
		Reduction							Carbon equivalent t/a
Action/ measure	**Level**	**CO_2 t/a**	**CH_4 t/a**	**N_2O t/a**	**CFC-11 t/a**	**CFC-12 t/a**	**HFC-134a t/a**	**HCFC-22 t/a**	
MOBILE1	1	0	0	0	0	1996	-1996	0	12 175 600
MOBILE2	2	0	0	0	0	1050	-1050	0	6 405 000
MOBILE3	3	0	0	0	0	212	-212	0	1 293 200

SOURCE: Global warming potentials (carbon equidioxide valences) of compounds are from IPCC 1990.

NOTE: Data are from Appendix A for the indicated actions which correspond to different years of introducing HCFCs or HFCs into air conditioners in new vehicles.
Carbon dioxide equivalences of actions are the sum of the product of the quantity and the GWP.
Data represent reductions in emissions in year 2005.

B.2 Estimation of private or social costs

The model provides for the possibility of estimating private, public and social costs. Private costs are the costs borne by private actors to reduce their emissions. These may include capital expenditures, operating and maintenance costs. In addition, the costs seen by the private sector may be increased or decreased as a result of measures adopted. For example, a grant might be provided to offset part of the capital cost associated with investment in equipment that reduces greenhouse gas emissions.

Public costs include capital and operating costs that must be incurred to implement a measure. These would include, for example, costs associated with inspectors to monitor compliance with a regulation or to collect a tax. Where the measure involves a transfer of funds between the private and public sectors, the two must be equal. Thus the dollar value of a subsidy given by the government decreases private costs and increases public costs by exactly the same amount.

Social costs are assumed to be the sum of private and public costs. Other social costs and benefits (e.g. the value of environmental damage or repair) are not incorporated into the analyses but are shown on the action and measure summary sheets.

Costs are calculated for the year 2005 by amortizing capital costs over the lifetime of the action (or measure) and adding the operating costs. If there is a subsidy, it is subtracted when calculating private costs and added when calculating public costs. The discount rate used for annualizing capital costs is chosen depending on sectoral considerations, or whether private or social costs are being calculated. The discount rates used real rates of three per cent for the municipal sector and social cost estimates, and six per cent for the private sector.

For some actions, implementation will have to occur in advance of 2005 in order to effect reductions in that year. For these actions, costs are increased to reflect the opportunity cost of these funds between implementation and realized emissions reductions in 2005. The overall equations are as follows:

$$S=P_u+P_r$$

where: S is the social costs ($1990 dollars in 2005)
P_u is the public costs ($1990 dollars in 2005)
P_r is the private costs ($1990 dollars in 2005)

$$P_u=(A_{cm}+A_{om}+I)\times(1+i)^{2005-t_i}$$

where: A_{cm} is the annualized capital cost of the measure (1990$ in 2005)

A_{om} is the operating costs of the measure (1990$ in 2005)

I is the incentive offered by the public sector to promote adoption of the action (1990$ in 2005)

i is the discount rate (percent)

t_i is the year in which implementation must occur to effect emissions reductions in 2005)

$$P_r=(A_{ca}+A_{oa}-I)\times(1+i)^{2005-t_i}$$

where: A_{ca} is the annualized capital cost of the action (1990$ in 2005)

A_{oa} is the operating costs of the action (1990$ in 2005)

For the examples, the calculated costs of the action are as reported on the action summary information sheet, and as summarized in Table B-2.

Table B-2 Summary of calculation of annualized cost of action

Action code	Capital cost	Annual capital cost A_{ca}	Annual operating cost A_{oa}	Delay $(2005-t_i)$	Annual cost P_r
MOBILE1	$571 638 825	$77 667 400	$246 947 972	10	$581 336 691
MOBILE2	$300 716 766	$40 857 773	$129 909 643	5	$228 525 324
MOBILE3	$60 797 988	$8 260 498	$26 264 731	1	$36 596 743

NOTES: Action codes refer to the coding in Appendix A
Capital cost, annual operating cost, and delay are from the Action Information Summary Sheets
Annual capital costs for these actions are based on lifetimes of 10 a, and a 6% real discount rate (as indicated on the action information summary sheets)

B.3 Determination of incremental unit costs

For a number of emission sources, there may be multiple actions or multiple ways of implementation. Once annualized costs are calculated for each measure, incremental unit costs are calculated. Before this can be done, it is necessary to determine whether the action and measure combination applies uniquely to a particular emissions source. If it does, then the incremental unit cost is the same as the average cost, or total cost divided by total tonnes.

In many cases, we have attempted to estimate cost for more than one action, or more than one level of an action that apply to an individual emissions source. In these cases, it is necessary to calculate the incremental unit costs as one steps from the action with the least emissions reduction to the action with the greatest emissions reduction. For example, with rigid foams made using CFC-12, it is possible to cut CFC use in half with reduction measures, or a substitute blowing agent—HCFC-22—may be used. The first action will halve CFC use (and hence emissions), where as the second eliminates all CFC-12 use; the first action is free, the second involves a modest equipment cost. Similarly, for some actions, including chemical substitution of HCFCs it is possible to achieve greater reductions with earlier implementation, but at a greater cost. The costs and incremental costs of such an example are indicated in Table B-3.[14]

B.4 Construction of the abatement cost curve

The abatement cost curve is constructed by plotting the sorted incremental unit costs, (and the average unit costs) against the cumulative reductions. Data from the action summary information sheets in Appendix A, sorted in this way, are presented in Table 16, (page 77).

[14] In some cases, it was necessary to sub-divide some of the actions so that they could match comparable actions. Specifically, landfill methane recovery costs vary with scale and the availability of markets for energy recovered, as reflected in actions LFG2 through LFG19. The other waste management actions were sub-divided to correspond to these different landfill gas recovery situations. For example, the incineration action (LAND15) is made up of large scale units that are applicable in communities with large landfills. For estimating incremental costs, it was thus necessary to sub-divide LAND15 into LAND15a and LAND15b that corresponds to the large (500 000 t/a) landfills in LFG10 and LFG19 respectively. Actions LAND1 through LAND6, LAND 13 and LAND15 through LAND 18 were sub-divided in a comparable way.

Table B-3 Example of estimating incremental unit costs where there are different implementation timetables

Action code	Reduction kt-CE/a	Cost M$/a	Incremental reduction kt-CE/a	Incremental cost M$/a	Incremental unit cost $/t-CE
MOBILE3	1 293	$36.6	1 293	$36.6	$28.30
MOBILE2	6 405	$208.9	5 112[a]	$172.3[b]	$33.71
MOBILE1	12 176	$581.3	5 771	$372.4	$64.53

NOTES: [a] The incremental reduction from implementing in 2000 rather than 2004 is (6 405 - 1 293 =) 5 112 kt/a. The reduction is greater because more vehicles are affected.
[b] The incremental cost of implementing in 2000 rather than 2004 is ($208.9 - $36.6 =) 172.3 M$/a, reflecting both the number of vehicles and interest costs on earlier vehicles. The incremental unit cost is the incremental cost divided by the incremental reduction.

Appendix C Measures applicable to specific emission types

This appendix reviews the major sources of greenhouse gas emissions and the actions that are applicable to them, and considers measures that might be applicable to them, based on the general categories of measures and the criteria outlined in Section 7.2. The review of measures is necessarily qualitative, and further research will be required to quantify the specific costs and effects of identified measures.

C.1 CFC emissions

The most pressing environmental justification for reducing production and emissions of CFCs is to protect the stratospheric ozone layer as a filter of ultraviolet radiation. In this regard, the main additional concern introduced by global warming considerations is to ensure that any substitutes for CFCs contribute minimally to global warming. Apart from this, the measures for decreasing emissions of CFCs are the same for protection of the ozone layer or global warming.

Table C-1 Measures for CFCs

Control factor	Economic instruments	Regulatory measures	Information measures
Emissions			
Inputs		ban and sunset uses	research on alternatives
Outputs	deposit-refund systems subsidize CFC recovery		programs to encourage CFC recovery
Technology	tax incentives for conversion to non-CFC technologies	upgrade technology standards	R&D on improved technologies
Operation	performance bonds against major leaks	operating standards require maintenance to avoid leaks/losses	industry consultations on means to reduce losses
Situation		require special measures in situations vulnerable to spills/leaks	

The long term solution for CFCs is to phase out their production and use, to be replaced with substitutes with much less ozone-depleting and global warming potential. This is a process that is already well under way. The phasing out of CFC use in plastic foam is a relatively costless first step.

CFCs in use must also be recovered and recycled or destroyed. The destruction of the CFCs would be the preferable option, if there are less harmful substitutes at acceptable costs. In general, it would be very difficult to enforce a simple requirement that CFCs and CFC-containing materials and equipment should be returned for CFC destruction, because of the difficulty of monitoring disposal. This suggests that there must be no cost and possibly a refund for CFC recovery. In the case of CFCs already in use, this calls for a subsidy of CFC recovery. In the case of CFCs to be produced and put into use before they are phased out, a deposit-refund system is a possible measure. It would likely be simpler, however, for a simple tax or charge to be

applied to CFCs, and have the subsidy for the recovery of "new" CFCs the same as that for "old" CFCs.

For large-volume uses of CFCs (e.g. industrial refrigeration), it is likely to be more feasible to monitor use, and therefore to *require* replacement and destruction of CFCs. At least, if it is possible to detect major leaks, performance bonds against such leaks may be a policy option. Even in the case of large-volume uses, however, compliance would likely be better ensured if there was an incentive for CFC recovery and destruction, such as a deposit-refund or tax-subsidy system. These incentives could also include tax-based incentives to phase out CFCs, and materials and equipment that require them.

Although these economic instruments should address the main elements of a program to recover and destroy CFCs, they might also be supplemented by regulatory and information measures.

C.1.1 Applicability

Of the principal proposed measures, subsidization of CFC recovery and destruction in the case of those already in use would require a reliable means of auditing the quantities recovered and destroyed. A deposit-refund or tax-subsidy system for "new" CFCs would present the additional complication of having to collect (at either the wholesale or retail level) the deposit or tax on CFCs in equipment or materials that are manufactured or imported into the jurisdiction. Requirement of a substantial deposit or tax may prompt purchasers of such equipment or materials to attempt to evade the deposit by importing them from outside the jurisdiction. If this is the case, compliance might be more reliably and efficiently ensured by instituting the deposit-refund or tax-subsidy system at the national, rather than provincial level, because of the greater capacity on the part of the federal tax and excise system to collect the deposit on both domestic products and imports.

C.1.2 Effectiveness

The effectiveness of the measures will depend on how many uses of CFCs they can be efficiently applied to, and the degree of compliance for each of these uses.

C.1.3 Efficiency

It should be possible to implement measures to phase out the uses of CFCs in plastic foams at relatively small administrative cost by voluntary industry compliance, and possibly information measures aimed at industry to secure compliance and at consumers to encourage purchase of non-CFC products. Developments in these areas are already taking place at the federal and provincial levels.

The efficiency of the measures will depend on the costs of administering and implementing CFC recovery and destruction, whether with a tax-subsidy or deposit-refund system. It would generally be more efficient to apply a uniform subsidization system for CFC recovery, whether or not a "tax" is also imposed on new CFCs. The tax would also contribute to efficiency by discouraging dispersive uses of CFCs. Such a tax is also likely to be generally acceptable, especially if its proceeds are allocated to CFC recovery or reduction.

The effect of administrative costs on the overall costs of measures can be illustrated by the case of recovery and destruction of CFCs prior to disposal of a motor vehicle (MOBILE5). This measure would need to be applied to only an estimated 14 wrecking yards in Ontario. The administrative costs of this measure could include:

- initial costs of requiring wrecking yards to install CFC recovery equipment,
- initial and ongoing costs of training wrecking yard personnel to recover CFCs,
- costs of monitoring performance.

Of these costs, the last is likely to predominate. Assume that these administrative functions could be performed by a government staff of at most 4 people with appropriate office support at a cost of roughly $400 000 per annum. These administrative costs would add approximately 2% to the incremental unit cost of the action of $8.64 per tonne to give an incremental unit cost of the measure of $8.81 per tonne. Therefore, the ranking of this measure should not be affected by these administrative costs, because the incremental unit cost of the next action (LFG8) is $9.49 per tonne.

C.1.4 Equity

In general, the subsidization of CFC recovery and destruction is contrary to the polluter pays principle. Nevertheless, considering that most people in Canada have benefitted from CFC use, at least in refrigeration, the equity aspect of the polluter pays principle should not be violated substantially by the subsidization measure. Given what is now understood about the environmental effects of CFCs, and the existence of alternatives, it would accord with the polluter pays principle if future production and use of CFCs is subject to a charge or tax.

As in previous cases, the allocation of joint costs and benefits is not an issue for CFCs, because the polluter pays principle would apply to all of the benefits of reducing losses, including the ozone protection benefits, as well as the GHG reduction benefits.

C.2 Livestock emissions

Methane is produced both from the flatulence and manure of livestock (especially cattle). The measures for these emissions are discussed together here, because some changes (e.g. modifying livestock diets, or encouraging less human consumption of meat and dairy products) could affect both. Measures for livestock emissions are suggested in Table C-7.

As with landfill emissions, it is impractical to monitor livestock methane emissions directly. Nevertheless, these emissions can be expected to be directly related to numbers of livestock and their diets. This suggests three actions that measures could promote to reduce livestock emissions:

- reducing the numbers of livestock (especially cattle);
- changing the diets (or supplements) of livestock; and
- reducing or recovering methane emissions from livestock manure.

The latter two actions are also areas for research and development (e.g. for reducing or modifying the microorganisms in the digestive systems of livestock that are responsible for the generation of methane).

Table C-2 Measures applicable to livestock emissions

Control factor	Economic instruments	Regulatory measures	Information measures
Emissions			
Inputs	head tax on cattle		R&D and advice on livestock supplements
Outputs	tax meat and dairy/ incentives for manure tanks and gas recovery/ revise NUG rates	require manure tanks and gas recovery	reduce meat and dairy consumption/ promote gas recovery
Technology		require gas recovery systems	training and R&D for gas recovery systems/ R&D of other methods
Operation		operation standards for gas recovery systems	
Situation			

Numbers of livestock

The numbers of livestock depend on the demand for meat and dairy products, and the prices at which these products are available to consumers. Even ignoring the unaccounted costs of GHG emissions (and other externalities), it can be argued that the prices of these products are artificially low (and consumption too high) because of agricultural subsidies. However, this is offset to some degree by supply management programs that restrict supply, and therefore raise prices. Nevertheless, the elasticities of demand for these products are generally accounted to be quite low, so that relatively large increases in prices would be required to reduce consumption significantly.

The other means of reducing consumption of meat and dairy products is by lessening demand for these products by encouraging consumers to change their diets. There is already some basis for such changes on the basis of health. Nevertheless, there is also

considerable advertising effort in Canada, sponsored by the supply industries, to *increase* demand for these products. Policies to change demand are outside the usual scope of economic analysis where consumer demand is assumed as given. Without a given level of consumer demand the basis for evaluating costs and benefits in economics is indeterminate.

Policies to influence demand also have to be evaluated on a broader basis than their economic benefits (e.g. their contributions to sustainability) or by applying some other measure of benefits than consumer demand (and consumer surplus). In the case of changes in diet, these benefits might include health benefits and other environmental benefits, as well as changes in GHG emissions.

Changes in livestock diet

The second possible approach to reducing livestock emissions is by changes in livestock diet. Reducing emissions could involve substantial changes in livestock diets that would considerably affect the economics of livestock production. The exception to this general proposition is specific injections or diet components that directly affect livestock metabolism (e.g. rBST for cattle) or the activity of the microflora in livestock digestive systems that generate methane. Those compounds that are not already in use are under research or review for other intended benefits. In this context, the most appropriate measure could be merely to suggest that GHG reduction benefits should be taken into account with other benefits in evaluating livestock supplements. This measure could also encompass support for research to evaluate supplements in this regard, and even to develop new supplements specially for this purpose.

Emissions from livestock manure

The action that could contribute most immediately to reducing livestock methane emissions would be to reduce or recover these emissions from livestock manure. The policy considerations for this option are similar to those for landfills. In the case of livestock methane sources, however, it would likely be much more difficult to require gas recovery systems and monitor their efficient operation because there are many more of these sources than landfills, and the factors that affect efficiency of gas recovery are more difficult to monitor. This suggests greater reliance in this case on measures to strengthen incentives for gas recovery for energy. Again, this would mainly be through the provision of capital for gas recovery systems at the low interest rates paid by energy utilities, and rebates per unit of energy generated from gas recovery of the difference between the true cost and the rates charged for delivered energy from utilities. Apart from livestock manure gas *recovery*, which may be too costly in many situations, means could be investigated for reducing emissions from

livestock manure, such as spreading the manure to encourage aerobic, rather than anaerobic, decomposition. Other considerations, such as odour, may be important here, however.

In summary, this analysis suggests three broad measures for reducing livestock emissions:

- collaboration with health and environmental organizations to influence consumption of meat and dairy products;

- considering GHG reduction benefits in directing agricultural research and extension with regard to livestock feed and supplements; and

- instituting incentives for gas recovery for energy that are correct in terms of the true opportunity costs of provision of this energy by utilities.

Evaluations of these measures in terms of the criteria are as follows.

C.2.1 Applicability

Each of the measures could be implemented both by the federal and provincial governments. For the last measure, however, there is greater scope within provincial jurisdiction for measures directed through, or compensating for, the policies of the energy utilities.

All of the measures should be easy to administer, because they merely involve modifications of the direction of policy in the public sector.

C.2.2 Effectiveness

The only measure with potential for identifiable GHG reductions in the short term is the measure for livestock gas recovery. The other measures are intended to modify the longer term direction of agricultural production. The potential effectiveness of gas recovery is indicated by the amount of gas that would be recovered if pricing incentives were correct: this addresses only methane from manure and not methane from gastric fermentation.

C.2.3 Efficiency

As already indicated, measures to reduce the consumption of meat and dairy products cannot be evaluated in the usual terms of economic efficiency, that take consumer preferences as given. Rather, some other basis of economic efficiency that modifies consumer demand, perhaps based on a rationale of imperfect consumer information, would have to be applied.

Measures to encourage consideration of methane emissions in the development and use of livestock feed and supplements is directed to a kind of dynamic efficiency. Among some researchers, there is believed to be a good prospect of practically eliminating the rumen microflora that generate methane by replacing them with other, possibly genetically engineered, microorganisms that generate little or no methane. If this is the case, such a development could practically eliminate livestock methane production and obviate the need for the other measures.

The efficiency of the measure to encourage recovery of gas from manure would depend on the successfulness in getting correct incentives for gas recovery, given the opportunity costs of providing energy from utilities. Given the current incorrect incentives, there is scope for corrective policies that could both increase economic efficiency and reduce livestock methane emissions.

C.2.4 Equity

Reductions in consumer demand for meat and dairy products could be expected to decrease incomes of producers of these commodities. If this was a result of a deliberate government policy, there could be some expectation of redress on the part of these producers. Such an expectation would be more difficult to maintain if government policy was instead directed to reducing market distortions from present policies that result in excessive production of meat and dairy products.

Changes in agricultural technology, such as new livestock feed and supplements or gas recovery systems, can put small farms at a further competitive disadvantage against larger, capital intensive farms. This issue of equity may also arise with regard to policies to reduce or recover livestock methane. Therefore, some attention may need to be given to ensure that programs and new technologies are made available to all sizes of farms.

A head tax on cattle or taxes on meat and dairy products would likely be regarded as regressive (inequitable) since consumers or producers are asked to pay a fixed amount per purchase or sale regardless of income.

C.3 Natural gas utility emissions

The analysis of actions suggested that methane emissions from natural gas utilities derived from small equipment leakages, losses during maintenance, and accidental rupture of pipelines (often by parties digging without checking for the presence of pipelines). Measures to support actions to reduce these emissions are suggested in Table C-7.

Table C-3 Measures for natural gas utilities

Control factor	Economic instruments	Regulatory measures	Information measures
Emissions			
Inputs		require lower pressure in pipelines	
Outputs	gas demand side management		gas demand-side management
Technology	allow pipeline upgrading to be added to rate base	revise/raise standards ban pneumatic valves	R&D on improved technologies
Operation	performance bonds against major leaks increase liability	require maintenance to avoid leaks/losses	promote industry consultations on means to reduce losses programs to reduce accidental ruptures
Situation		require special measures in situations vulnerable to spills/leaks	

Although it is impractical to measure pipeline losses directly, gas utilities record "unaccounted losses" as the difference between the quantities of gas input and output from a pipeline. It is not always clear, however, that these unaccounted losses result from leakages. Therefore, imposing charges on unaccounted losses may be inappropriate in targeting leakages, and they may also have an effect of distorting the way that pipeline operators record and report unaccounted losses.

To the degree that the frequency of major leaks and explosions is an indication of continuous gas losses, then enhanced liability for leaks and explosions may increase the incentives for reducing gas leaks. If liability in common law is insufficiently effective, a system of performance bonds may provide more effective incentives. Performance bonds generally accord with a legal regime of strict liability, but additional liability may be warranted in cases of negligence.

Policy development for natural gas utility leakages can begin by acknowledging that there is already an incentive for utilities to avoid losses of gas (before it reaches the consumers' meters), because such losses result directly in losses of revenues. Nevertheless, to the extent that the profitability of utilities depends more on the rate base assessed by regulators than on short-term revenues, this incentive may be ineffective. Then, as indicated in the table, allowing pipeline upgrading to be added to the rate base may provide a more effective incentive. Pipeline upgrading could also include improvement of equipment to detect and repair leaks.

Especially if there has been inadequate incentive to reduce gas losses, there may also have been insufficient investment in information activities, such as research, development, consultations and training. These deficiencies may be addressed directly by governments through policies to encourage such activities. In particular, consultations among the parties responsible in industry and governments could help to better identify the causes of gas losses, and define the best technical and operational means of avoiding such losses.

These industry consultations could also lead to new technological and operating standards for the natural gas utilities. If deemed appropriate within the context of these continuing consultations, such standards could also be supported in part by regulation and by economic instruments to encourage compliance.

To enhance sharing of information and technology, consultations could be carried out at national and international levels, as well as at the provincial level. This would be helpful not only in reducing emissions within Ontario, but also in reducing emissions in other jurisdictions, that are often a larger fraction of the gas transported, and that contribute to global warming equally on a unit basis to emissions from Ontario. To add to the comprehensiveness and prestige of this undertaking, engineering professors and representatives of standards organizations could also be requested to participate in the consultations, along with industry and government representatives.

C.3.1 Applicability

The measures for the natural gas utility emissions are somewhat broader and more integrative than those for other emissions. This reflects the more uncertain and tenuous incentive and information structures of a regulated public utility.

Regulation and the application of economic instruments to reduce methane emissions from gas utilities is within provincial jurisdiction. In practice, it will be necessary to delimit what kinds of pipeline upgrading could be added to the utility rate base, and

this could be done together with standard-setting to provide a means for verifying the upgrading.

Although information measures, particularly industry consultations, could be sponsored at the provincial level, there would also be advantages, as suggested previously, in instituting them at the national and international levels.

Both economic and information measures should be easy to administer with few major companies subject to the measures. Some consideration would be required as to whether the measures should apply only to pipeline distributors of gas, or also to bulk distributors. Changes in the capital expenditures that qualify for addition to the rate base would require approval of the Ontario Energy Board. The other economic and regulatory measures could be implemented on the basis of relatively minor changes and extensions of current policy instruments.

C.3.2 Effectiveness

The effectiveness of measures to reduce natural gas leakages will depend on the fractions of the total leakages attributable to different causes. The major causes of gas emissions (not necessarily in order of magnitude) are:

- leakages from failures in equipment used in the pipeline system;
- venting during routine maintenance; and
- accidental pipeline ruptures.

This suggests that the most effective measures will be those that affect the upgrading of equipment directly, and those that encourage good operations and maintenance practices.

C.3.3 Efficiency

In principle, if it is assumed that the marginal cost of reducing leakages increases without limit as leakages are reduced to zero, allowing pipeline upgrading to be added to the rate base would be efficient only up to some "optimal" level of leakages at which the marginal cost is equal to the (marginal) benefit of methane emissions reduction (or the optimal tax rate for methane). Then, standards should be set at this level, and adding of costs to the rate base should only be allowed up to the level necessary to meet these standards. Determining the appropriate levels of these standards would call for cost-benefit analysis (or risk-benefit analysis), in which the cost of the contribution of methane leakages to global warming would be included (among other potential costs of leakages). The measure of allowing the costs of meeting these higher standards to be added to the rate base should have little or no administrative cost because it is a minor change within the regulatory regime, and would not require more extensive regulation.

Performance bonds could also be an efficient policy measure to the extent that major leakages are detectable. The costs of administering a performance bond system should also be low, but there could be substantial costs in the event of disputes over failures of performance. Therefore, efficiency, as well as the other criteria, require that the condition of failure of performance be clear and indisputable.

The efficiencies of the other measures are more difficult to assess in the absence of a more thorough assessment of the actions that they are intended to induce. In particular, the efficiency of information measures will depend on the scope for improved information, technologies and management practices to reduce emissions.

With regard to dynamic efficiency, there is no incentive to improve technologies with regulations or economic instruments (such as allowing costs to be added to the rate base) that are based on meeting current standards. Only measures that create incentives to improve on the current standards, such as performance bonds or strict liability, contribute to technological improvement and dynamic efficiency. Dynamic efficiency may also be promoted by the information measures, especially the industry consultations, to the extent that these increase the effectiveness of response to any measures, by helping to pool resources and knowledge toward improvements in technologies and practices. The industry consultations could even be guided to lead to formation of an industry consortium to support R&D.

C.3.4 Equity

The equity of measures will depend on the efficient operation (efficient operation means a firm which profit maximizes or cost minimizes) of the regulated gas utility. Simply, regulated gas utilities possess some monopolistic market powers. Thus the efficient operation of the gas utility cannot be assumed to be the same as for a firm in a perfectly competitive market. In particular, utilities may not minimize their costs in responding to incentives or complying with regulations if they can simply pass on *all* costs in higher rates to consumers. Incentives must bear on profitability if they are to be effective. Regulated gas utilities profits are often fixed by government regulation and thus unaffected by such incentives.

As such, the equity properties of the polluter pays principle may be compromised to the degree that utilities (individual firms) are not induced to behave efficiently by the regulatory regime, resulting in an inequitable distribution of the costs of the measure.

Similarly, the funding of information measures should ultimately be borne by the utilities rather than be drawn from governments' general revenues in order to meet the terms of the polluter pays principle. This addresses the equity consideration that gas producers and users should bear all costs, rather than leaving some to be borne by the general public.

As in previous cases, the allocation of joint costs and benefits is not an issue for natural gas losses, because the polluter pays principle would apply to all of the benefits of reducing losses, including the safety benefits, as well as the GHG reduction benefits.

C.4 Landfill methane emissions

Table C-7 indicates some of the policy measures that appear applicable to landfill methane emissions. Note that if landfill gas is released it is an "emission"; if it is captured it is an "output".

For landfill gases, as for most GHG sources, it is difficult to monitor emissions directly. Nevertheless, the emissions can be expected to be an increasing function of the quantity of organic material in the landfill. As already noted, it is often economical to recover landfill gas for energy on sufficiently large landfills, and it may otherwise be needed to avoid safety or odour problems. This suggests that the main line of direct measures that can be adopted for landfill gas is to encourage, or even

Table C-4 Measures applicable to landfill methane emissions

Control factor	Economic instruments	Regulatory measures	Information measures
Emissions			
Inputs	organics tipping charge foster compost market	ban organics from landfills require composting	demonstrate alternatives (e.g. composting)
Outputs	charge unrecovered gas revise NUG rates	require gas recovery	encourage uses of landfill gas
Technology		require recovery systems	training and R&D for gas recovery systems
Operation		monitor gas recovery	
Situation			

require gas recovery on sufficiently large landfills. This policy might be supported by an economic incentive in the form of a charge (tax) on fugitive methane emissions from landfills as *inferred* from the quantities of organic waste in the landfills and any direct measurements.

If this charge is set at the level of the optimal tax, it should provide the appropriate incentive to consider GHG contributions in decisions on whether to install gas recovery systems, and to raise tipping fees for organic wastes. The raising of tipping fees for organic wastes should discourage their disposal with other wastes at landfills, and thereby encourage other means of managing them, such as composting.

The analysis of actions indicated that if charges (e.g. tipping fees) were to be set to reflect true social costs, composting (whether home composting or municipal composting) would be the least cost method of reducing methane emissions from landfills. Composting has a net benefit per unit of methane emission avoided even greater than the net benefit per unit from recovery of landfill methane. Furthermore, this benefit can be realized at practically any scale of composting, unlike the case of landfill gas recovery where net benefits require a minimum scale. If this is the case, the current minor role of composting can be attributed to one or more of:

- incorrect pricing (e.g. tipping fees), not reflecting real social costs;

- lack of information about composting on the part of municipal officials and the public;

- absence of, or imperfections in, markets for compost from municipal waste; and

- incorrect assumptions about the time and effort of the waste generator to compost or source separate.

All of these considerations suggest that effective and efficient measures for landfill methane emissions should induce the result that *would* be achieved *if* an optimal tax on methane emissions from landfills were imposed. The two essential complementary measures for this are:

- a requirement for gas recovery on landfills where the net social benefits are positive (taking into account the social costs of methane emissions at the optimal GHG tax rate); and

- tipping fees set at the true social cost of landfilling, including the social costs of any fugitive methane emissions (at the optimal GHG tax rate) in the case of organic wastes.

The effectiveness of these measures could be further enhanced by measures to encourage efficient alternatives to landfilling of organic wastes. In particular, in the case of composting, this could include fostering greater awareness of composting techniques, and strengthening markets for compost from municipal waste. These latter measures could be funded in part by the additional revenues from increased tipping fees.

Similarly, an economic incentive for landfill gas recovery could be provided by revision of non-utility generation rates to better reflect the value of this energy source in terms of the opportunity cost of providing the energy to users from other sources. In particular, capital for gas recovery systems could be made available at the same low interest rates as those available to utilities.

Results from application of the evaluation criteria to the two essential measures for landfills are as follows.

C.4.1 Applicability

Both measures are within provincial jurisdiction, but would be facilitated by cooperation from municipalities and landfill operators. The increase in tipping fees might induce illegal disposal or diversion of wastes to other jurisdictions. Illegal disposal can be addressed by other measures or enforcement, but diversion of wastes would be difficult to control.

Both measures should be easy to administer, because there are relatively few major landfills. In the case of the gas recovery requirement, it is easy to monitor installation of the gas recovery systems, but continuing monitoring will be required to ensure their efficient operation. In the case of raising tipping fees, a formula will need to be devised, and its application monitored, to collect the increased revenue and divide it appropriately between the landfill operator and the Province, according to the fraction of gas recovered, in order to provide the correct incentive to landfill operators for gas recovery.

C.4.2 Effectiveness

The potential reduction in emissions by means of landfill gas recovery is limited by the quantity of emissions that can be recovered from those landfills that are sufficiently large or have other characteristics for gas recovery to be economical. The potential reduction in emissions by diversion of organic waste from landfills to uses or disposal that do not generate methane is the amount of methane that would be generated in a landfill from which the waste is diverted. In the *long term*, diversion of organic wastes from landfills could eliminate this source of methane.

The technology for landfill gas recovery is readily available and effective. Nevertheless, some planning is generally required for efficient use of the recovered gas for energy. This raises issues of non-utility energy generation and the rates that should apply to these energy sources.

The effectiveness of increasing tipping fees for organic wastes will depend on the response to this incentive for separating and diverting these wastes. This will largely be determined by the intermediate role of municipalities. The Province can adjust its transfer payments and other programs to encourage municipalities to try innovative programs for waste management that address landfill methane emissions among the many other aspects of this issue.

For the same reasons that little difficulty was found in the applicability of these measures, their enforceability should also be quite straightforward.

C.4.3 Efficiency

The private costs of the gas recovery requirement consist mainly of the initial capital costs and operating costs of the gas recovery systems, borne by landfill operators. If these costs are not recovered from energy generation, they will need to be recovered from other sources. Under a generalized "polluter pays principle", these costs should be recovered from those who contributed organic wastes to the landfill, in proportion to their contribution. Since such a system would be difficult to administer and enforce, any cost recovery is more likely to come from the successor population of current contributors to the landfill, in the form of higher tipping fees that would be financed either by higher taxes or a "pay by the bag" waste collection system.

The analysis of actions indicated that there are net benefits to the municipalities from separating organic waste for composting, either in home composters or municipal facilities.

The public, administrative costs of both measures should be low because both were found to be easily applicable and enforceable. These costs should be negligible compared with the costs of the actions in determining the overall efficiency of these measures.

With regard to dynamic efficiency, the requirement to recover landfill gas will not of itself provide an incentive for the improvement of gas recovery technologies and methods. There will only be such an incentive if there is a benefit from energy recovery directly related to the gas recovery. Thus, energy recovery contributes to dynamic efficiency. It could also help to reduce the costs of public monitoring and enforcement, since the incentive for the gas recovery system to be operated efficiently could be assumed.

C.4.4 Equity

Both measures are broadly consistent with the "polluter pays principle", which can be considered to be one of the criteria of equity, as well as of efficiency. The only departure from this principle occurs if current contributors of waste to landfills bear the costs (or benefits) in tipping fees of gas recovery from waste from previous contributors.

The costs of both measures would ultimately be born by landfill operators and waste generators, except possibly for the costs of monitoring and enforcement and any costs of information activities conducted by the public sector. The costs of monitoring and enforcement might be recovered, at least in part, by the public sector through administrative charges or user charges.

These measures to reduce landfill methane emissions would be equitable with measures to promote other actions if the increase in tipping fee to reflect the cost of the contribution of methane emissions to global warming was commensurate with the same implicit "optimal tax" rate that would be applicable to other methane emissions or GHG emissions generally.

C.5 Adipic acid

Since adipic acid production is already being phased out in Ontario, and no actions were found necessary, no measures are considered.

C.6 N_2O anaesthetic

Since no actions were deemed appropriate in the case of N_2O as an anaesthetic, no measures are considered.

C.7 Nitrogenous fertilizer

The means for reducing N_2O emissions from the use of nitrogenous fertilizer apply to the *types* and *amounts* of fertilizer used and the *method of application*. Potential measures are indicated in Table C-7. In some situations, these measures could also have substantial environmental benefits in reducing nitrification of surface and ground waters.

Table C-5 Measures applicable to nitrogenous fertilizers

Control factor	Economic instruments	Regulatory measures	Information measures
Emissions			
Inputs	tax fertilizers per their likely emissions	ban high emitting fertilizers (e.g. anhydrous ammonia) if this reduces emissions	encourage less use of nitrogenous fertilizers encourage rotations with nitrogen-fixing crops as alternative
Outputs			promote production and consumption of leguminous crops
Technology			
Operation		restrict inefficient or polluting fertilizer application	encourage efficient fertilizer application
Situation			discourage fertilizer application where it most contributes to N_2O or other pollution

C.7.1 Applicability

There are special product charges (taxes) on nitrogen and phosphorus fertilizers in Norway and Sweden, intended to raise revenues for environmental programmes in the agricultural sector, and in Sweden also to act as an incentive to reduce fertilizers use (Opshoor and Vos 1989). The Swedish tax raised the prices of fertilizers by 5 per cent on average, but has not significantly affected their use, so the elasticity of demand appears to be low (Opshoor and Vos 1989).

Accordingly, although the revenue-raising potential of charges should not be ignored, it appears that in terms of reducing fertilizers use and N_2O emissions, the focus should be on the information and regulatory measures.

C.7.2 Effectiveness

In terms of reducing N_2O emissions from fertilizers, the most effective measure *might* be to ban high-emitting types of fertilizer, especially anhydrous ammonia. The costs and the likely behaviour of farmers in response to a ban would need to be carefully researched. The costs might be onerous in some situations where these fertilizers are especially suitable. Furthermore, the banning of these fertilizers may induce greater use of other fertilizers as substitutes which could largely reduce or offset the intended reductions in emissions.

This leaves information measures to reduce nitrogenous fertilizer use providing the main scope for emissions reduction. These measures are already being pursued to reduce costs, and alleviate soil degradation and nitrification of surface and ground waters. Reduction of N_2O emissions adds one more reason to pursue these measures. The effectiveness of these measures need to be assessed, however, especially with regard to their potential contribution to N_2O emissions reduction.

C.7.3 Efficiency

The tax on fertilizers at a rate related to the marginal cost imposed by emissions is theoretically consistent with economic efficiency. The experience of Norway and Sweden suggests that the administrative costs of such a tax need not be high, if they are applied at a national level. Theoretically, in the absence of administrative costs, bans are less efficient than taxes, but a ban may be easier and less costly to apply for the amount of product involved.

The efficiency of information measures depends on the degree to which farmers are encouraged to reduce nitrogenous fertilizer use by greater knowledge of consequences and alternatives. Trends toward reduced fertilizer use and organic agriculture are propitious in this regard.

C.7.4 Equity

Most of the potential measures are consistent with the Polluter-Pays Principle, although application of the tax, at least to raise revenues for the other measures, would enhance consistency with this principle. The ban on high-emitting fertilizers may raise other concerns with regard to equity, if some farmers are particularly inconvenienced by this measure. In most cases, however, it should be possible to substitute low-emitting for high-emitting fertilizers without imposing any special burdens.

C.8 Ammonia

As indicated in the section on actions for ammonia, 78% of ammonia production in Ontario is for manufacture of nitrogenous fertilizers. Therefore, reduction in use of nitrogenous fertilizers would not only decrease N_2O emissions from these fertilizers themselves, but also decrease N_2O and CO_2 emissions from ammonia production. Measures to reduce nitrogenous fertilizer use can be effective in both regards. Several other potential measures are suggested in Table C-7.

C.8.1 Applicability

All of the indicated measures could be applied within provincial jurisdiction, but a tax on ammonia or nitrogenous fertilizers might have negative impacts on the competitiveness for producers within the Province if the tax could not also be imposed on imports.

Encouraging less use of nitrogenous fertilizer would be an easy measure to administer, and to assess in terms of effectiveness. This is discussed more fully in the section on measures for nitrogenous fertilizers.

Table C-6 Measures applicable to ammonia production

Control factor	Economic instruments	Regulatory measures	Information measures
Emissions	tax or marketable permits for NO_x		
Inputs			
Outputs	tax on ammonia or nitrogenous fertilizers increase marketing and use of captured CO_2		encourage less use of nitrogenous fertilizers R&D for substitutes of other uses of ammonia
Technology	favour low-emission technologies in taxation		R&D ammonia making with less emissions
Operation		bid effective operation of emissions capture	
Situation			

The other measures would be more easily applied if they could be associated with other policy measures. For example, policies to reduce NO_x emissions (including proposals to do so through marketable permits) could be extended to include N_2O emissions from ammonia production.

C.8.2 Effectiveness

The effectiveness of reducing nitrogenous fertilizer use in Ontario for reducing emissions from ammonia manufacture will depend on the proportion of ammonia manufacture that goes to fertilizer for use in Ontario. A reduction in nitrogenous fertilizer use in Ontario might not induce a proportional decrease in fertilizer (and ammonia) production, if fertilizer production is maintained for export out of the Province.

The information on actions for emissions control in the ammonia sector suggests that the emissions control technologies that are currently used in this sector are potentially

highly efficient, although there may be some grounds for favouring especially low-emission technologies in taxation. Therefore, the measures that might be most directly effective for the control of N_2O emissions from this sector are those to encourage or provide regulatory supervision for the use and effective operation of these technologies.

C.8.3 Efficiency

Encouraging alternatives to nitrogenous fertilizer use could have other benefits for soil quality, reduction of soil erosion, and protection of groundwater. If these factors are taken into account, measures to reduce fertilizer use are likely to be generally efficient. This depends on a more detailed analysis of the use and alternatives to nitrogenous fertilizer use, which is beyond the scope of this study. Similarly, the efficiency of finding substitutes for other uses of ammonia needs to be examined.

On the basis of economic principles, a tax or marketable permits for NO_x emissions is likely to be efficient for reducing NO_x emissions generally. The implications for N_2O specifically need to be determined.

C.8.4 Equity

The equity considerations for increasing the costs or decreasing the output of ammonia production apply mainly to the few companies and communities involved in this industry. The means for reducing ammonia production and transitions to other economic activities need to be considered for these companies and communities.

C.9 Cement and lime manufacturing

The main actions for reducing non-energy carbon-dioxide emissions from cement and lime manufacturing are reducing the need for producing new calcium (or magnesium) oxide from carbonate by the calcining process. This can be accomplished by making use of ground granulated blast furnace (GGBF) slag and cement kiln dust, and by reducing the need for new concrete by extending the life, and reusing and recycling, the existing stock.

The potential measures for encouraging this, indicated in Table C-7, apply mainly to inputs and outputs. The most direct measures apply specifically to the calcination

Table C-7 Measures applicable to cement and lime manufacturing

Control factor	Economic instruments	Regulatory measures	Information measures
Emissions			
Inputs	tax calcium carbonates for use in calcination; form market for GGBF, CKD and used concrete		encourage use of GGBF and CKD as input substitutes
Outputs	tax virgin lime/concrete increase charges for disposal of concrete to increase reuse/recycling	improve standards for life of concrete	promote reuse/recycling of concrete
Technology			
Operation			
Situation			

process. A tax on calcium carbonate used in calcination, or on the calcium oxide produced, could be set at a level that would conform to the tax on carbon dioxide from other sources. Such a tax would encourage the use of input substitutes, such as GGBF and CKD, and raise the price of cement and lime produced from carbonates, thereby encouraging the recycling of existing stocks.

If it is believed that the barriers to these changes are not just a problem of incentives, addressed by economic instruments, but also a problem of lack of information or markets (e.g. with regard to substitutes), then regulatory and information measures may also be appropriate.

C.9.1 Applicability

It appears that the measures that would be easiest to apply would be to promote use of GGBF, CKD and used concrete by one or more of:

- creation or support of markets for these materials (e.g. with quality standards or grading)
- dissemination of information (and support of research) on the use of these materials
- increasing charges for their disposal

Taxing virgin lime/concrete or inputs to their manufacture might be difficult to administer, and the effects on the volumes of production might be minimal or uncertain. Nevertheless, although this might have minimal incentive effects, it could offer an acceptable means of raising funding to help to support the measures indicated above.

C.9.2 Effectiveness

The effectiveness of these measures derive from the potential calcination avoided.

C.9.3 Efficiency

It is difficult to assess the efficiency of these measures without greater knowledge of the current barriers to use of GGBF, CKD and used concrete. If these barriers could be overcome at modest expense for the calcination that could be avoided, then the suggested measures could be efficient.

The effects of taxes are at least as uncertain as the effects of the other measures, without knowledge of the elasticity of demand and long-term potential for substitution or avoidance of concrete in structures. Nevertheless, the tax options provide greater incentive for on-going improvements in techniques and practices to reduce the requirements for calcination.

C.9.4 Equity

The measures are generally consistent with the Polluter-Pays Principle, especially if a means can be established to recover the administrative costs of the measures from those engaged in calcination in proportion to the magnitudes of their production.

C.10 Pulp and paper

In the absence of definitive technical process changes for reducing CO_2 emissions from pulp and paper production, discussion of measures is premature. Support for R&D of such options may be warranted. Apart from technical process changes, CO_2 emissions from pulp and paper production could be reduced by greater recycling of paper to reduce the requirements for processing virgin timber. The efficiency of measures in this regard depends on the overall economics of recycling, which is beyond the scope of this study.

C.11 Raw CO_2

Since no actions were deemed appropriate in the case of raw CO_2 use, no measures are considered.

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